Nuclear Physics News

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Nuclear Physics News, Vol. 15, No. 3, 2005
The need for Ion Accelerators in Non-Nuclear Physics Fields

When ion implantation started to replace diffusion as a means for doping semiconductors, the market leader hesitated too long to install the new technology and was outrun by others. Admittedly, hardly anyone at that time had envisioned the huge impact ion implantation would have on the semiconductor industry, finally becoming a key technology in complex production lines. This success is directly linked to the comprehensive understanding of ion–matter interaction processes achieved at accelerators provided by the nuclear physics community. Theoretical models and simulation codes (such as TRIM) predicting the effect of elastic collision cascades were indispensable for optimizing production performances and developing ion beam technology in the low-energy regime (up to several hundred keV per nucleon). Many standard techniques, such as SIMS, PIXE, RBS, ERDA, and AMS are nowadays in regular use, mainly for materials analysis, with the general trend to smaller beam dimensions including focused ion beams for producing nanostructures.

The continuous drive of the nuclear physics community to higher energies at larger accelerator facilities offered new possibilities for research activities in application-oriented fields. In contrast to low-energy ions, ion-matter interaction with beams above about 1–3 MeV per nucleon are dominated by electronic processes with a huge energy deposition along the ion trajectory. There are no other means by which similar high-energy densities can be placed that deep in the bulk of materials. The large ion range in combination with the small track diameter of a few nanometers play a key role for numerous applications. Research performed at large accelerator facilities, mainly in Europe but with increasing intensity also in Japan, China, and India, is significantly improving the understanding of basic electronic excitation processes, track formation, and ion-induced degradation, and the tailoring of materials properties. The number of different topics addressed is enormous, ranging from studies of materials response to extreme radiation conditions (reactor material, nuclear waste storage), dating of geological minerals, fabrication of nano-objects, simulation testing of cosmic rays on electronic devices for space, to radiation effects on biological cells. Extensive basic research in this field has been essential for the development of hadron tumor-therapy, which is now emerging with several dedicated facilities in the construction or planning phase.

Considering the broad potential of swift heavy ions, the closing of the ion beam facility (Ionenstrahlabor ISL) at the Hahn-Meitner Institute in Berlin, announced for the end of 2006, caused a shock. After termination of the nuclear physics program, this machine has been exclusively devoted to basic materials research and applied activities including commercial membrane production and proton-therapy for eye tumors. The versatility and the high-duty cycle of the ISL machine provide most suitable beam conditions for irradiation experiments in materials science. The decision to shut down cannot be understood on the basis of scientific arguments because a recent evaluation rated the performed research as excellent.

Why is successful exploitation of energetic ion beams with spin-off applications in many disciplines not sufficient to justify the continued operation of a dedicated facility? Can these activities only coexist with nuclear physics? Even more important, what will happen if the permanent striving for higher energies in nuclear and particle physics continues, resulting in shutting down more and more smaller accelerators? How can the ion-beam community respond to additional tasks linked, for example, to the future fusion reactor project, ITER, or to incineration and transmutation of reactor waste in accelerator-driven reactor systems? At present, the beamtime schedule at large facilities is complex and usually overbooked. Experimental access involves slow proposal evaluation processes, a situation which is certainly not adequate for materials science, in particular if industrial partners are involved. A common European effort may help to improve access conditions by interconnecting high-energy accelerators of, for
example, GANIL, GSI, Legnaro, Munich, and Orsay to a virtual facility and setting up special arrangements such as beam-quota allocations and independent proposal and program committees. In any case, the risk that essential needs of the ion-beam community in applied disciplines will not be covered adequately in the future has to be seen as very large.

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The Saclay Nuclear Physics Division

The Nuclear Physics Division (Service de Physique Nucléaire, SPhN) of DAPNIA at Saclay in France is part of the fundamental research divisions of the CEA (Commissariat à l’Energie Atomique). Its programs cover a broad range of topics in Nuclear Physics from low to high energies. They include the study of the structure and dynamics of the nucleus, the structure of the nucleon, and the search for phase transitions of nuclear matter. SPhN also contributes to measurements and modeling of specific nuclear reactions related to nuclear waste transmutation. Furthermore, physicists apply their knowledge, competence, and techniques to the development of innovative nuclear energy cycles, to the production of neutron and radioactive beams and to the decommissioning of nuclear installations. The research activities take place within strong national and international collaborations involving the academic world and enabling the selection and training of high-quality students and post-doctoral researchers.

The Structure of the Nucleus

The objective of experiments in this area is to test and improve the descriptive and predictive power of nuclear structure models in the most extreme conditions with regards to nuclear isospin, angular momentum, mass, and temperature. Most of these experiments concern very unstable nuclei for which new phenomena such as very diffuse nuclear surfaces, clustering, low-lying resonances, or new magic shells appear that are not predicted by present models. The isospin dependence of the effective nucleon-nucleon force is a key ingredient of the models. One may expect that, along with other parameters of the effective force, such as the spin-orbit coupling or the pairing term, it will need to be readjusted for nuclei far from stability.

SPhN is involved in the study of the structure of light exotic nuclei such as $^6$He, $^{10,11}$C, $^{27}$Ne and in the study of shape coexistence in Kr isotopes. The experiments are performed at GANIL with beams delivered by the SPIRAL or SISSI facilities. It is also involved in experiments at Jyväskylä (Finland) to obtain information on the spectroscopy of fermium nuclei and especially on the structure of $^{251}$Md. Near-barrier and sub-barrier fusion of light unstable nuclei and their respective stable isotopes with $^{238}$U targets are studied at Louvain La Neuve (Belgium). Among the most significant experimental results, one can mention the remarkable sensitivity of inelastic scattering to the halo structure of $^4$He, studies on the structure of $^1$He (Figure 1), the first experimental evidence for a shape isomer in $^{12}$Kr (Figure 1) supporting the predicted scenario of prolate-oblate shape coexistence in this mass region and, by combining conversion-electron and gamma-ray spectroscopy, the first study of the structure of an odd fermium nucleus $^{251}$Md (Figure 2).

The experiments were realized with experimental devices constructed within the framework of national and international collaborations and with the participation of DAPNIA technical divisions. This encompasses participation in the construction of the silicon strip detector array MUST, of the segmented clover Ge detector EXOGAM, of the focal plane detection system of the VAMOS spectrometer and of the target chamber with a rotating target system dedicated to the study of the structure and production of heavy and super-heavy elements. SPhN is now participating in the development of experimental devices designed to measure with better efficiency, energy resolution, and granularity recoil particles (MUST2) and gamma rays (AGATA) produced in reactions induced by radioactive beams.

Nuclear structure physicists unanimously support the SPIRAL2 project, which aims to accelerate from 2009 radioactive beams produced by fission of uranium, and which will give access to beams of heavier nuclei than those obtained from the current SPIRAL facility. Medium- and long-range plans encompass participation in the new GSI project R3B and in elaborating the physics case for the European EURISOL project as well as in participating in its design and construction.

Nuclear Phase Transitions

Heavy ion collisions offer the possibility to create nuclear matter in the laboratory under extreme conditions of pressure and temperature. The purpose of our activities in this domain is twofold: the study of the liquid–gas phase transition in nuclei at relatively low incident energies and the search for the quark–gluon plasma at very high energies.

At relatively low incident energies, SPhN is involved in studies of the dynamics of heavy-ion collisions that aim at obtaining information on the equation of state of nuclear matter and concomitantly on the liquid–gas phase transition. This is an ingredient of nuclear dynamics governing stellar processes such as supernova explosions.
The main experimental tool for these studies is the 4π multiparticle INDRA detector, built with strong contributions from DAPNIA’s technical divisions. One of the quantities of interest in these collisions is the excitation energy of the nuclei formed before any particle emission. An outstanding result in this domain is the direct measurement of the thermal excitation energy of the primary fragments produced in central collisions between 32 and 50MeV/A. The experimental results are well reproduced by statistical multi-fragmentation models. These findings, combined with other experimental signatures, allow a better understanding of nuclear matter dynamics below 5MeV/A excitation energy.

At high temperatures and/or densities, QCD predicts a new form of matter, consisting of an extended volume of deconfined quarks, antiquarks, and gluons called the quark-gluon plasma (QGP). The aim here is to study the properties of this plasma, which is thought to have existed a few microseconds after the Big Bang.

SPhN participates in this search. Among the signatures of the QGP one of the most promising is the color screening of heavy resonances (J/ψ and Y) formed by pairs of heavy quarks and antiquarks. We study these resonances through their decay into pairs of muons in two experiments: PHENIX with the accelerator RHIC at (BNL) and ALICE at the LHC (CERN). These two experiments use a dimuon spectrometer for the detection of resonances. SPhN has contributed to the electronics of one of the dimuon arms of the PHENIX experiment and is actively participating in the construction of the dimuon arm for the ALICE experiment (Figure 3).
PHENIX is currently taking data at RHIC at nucleon-nucleon collision energy of 200 GeV. Results on $J/\psi$ production in Au-Au collisions will be available soon. A striking result obtained recently is the jet suppression observed at large transverse momentum. Indeed, data from the PHENIX detector show that the production rate of high-transverse momentum pions is suppressed in Au+Au collisions as compared to p+p or d+Au collisions. This result is compatible with suppression in a dense colored medium and could be the signature for the QGP formation.

ALICE is an experiment at the LHC (CERN), which is in the course of preparation and that will take its first data in 2008 at an energy about 30 times higher than that of PHENIX (5.5 TeV).

It is anticipated that the existence of the QGP will be firmly established at RHIC and its detailed properties studied at ALICE/LHC in the forthcoming years.

The Structure of the Nucleon

SPhN is involved in two experimental programs both using electromagnetic probes, one to obtain information on the spin carried by the gluons in the proton (COMPASS at CERN) and the other to extract information on generalized parton distributions by means of deeply virtual Compton scattering (CLAS at JLAB).

The contributions of quarks ($\Delta \Sigma$) and gluons ($\Delta G$) to the spin of the nucleon are accessible by using a polarized lepton beam and a polarized nucleon target. Recent experiments at CERN (SMC) and at SLAC, with strong participation by SPhN, have established that the contribution of the quarks to the spin of the nucleon is small. These results have been complemented by the HERMES experiment at DESY and it is now widely accepted that the quark intrinsic spin contributes only a small fraction (20–30%) to the total nucleon spin. These results agree with recent QCD calculations.
The main goal of the COMPASS experiment is the measurement of the gluon polarisation in the nucleon. DAPNIA has contributed to the COMPASS spectrometer by developing and building 12 micro-strip “micromegas” detectors (40×40cm²) (Figure 4) and 24 drift chambers (120×120cm²). These detectors are placed in the zone of high particle flux, immediately behind the target. Data taken in 2002 and 2003 have been analyzed. These data already provide competitive statistics for numerous channels: measurement of $g_1$ (better than SMC at small $x$), semi-inclusive scattering (already comparable to Hermes), coefficients of the $\rho$ meson spin density matrix, polarisation of the $\Delta$ (as good as NOMAD) and $\Lambda^-$ (much better than NOMAD). However, the main challenge remains the determination of the gluon polarization $\Delta G/G$. At the recent international conferences SPIN04 in Trieste and BARYONS04 at Palaiseau, the first results on $\Delta G/G$ from high transverse momentum hadron pairs were presented.

QCD also provides predictions for the transversity, which is the probability of measuring a quark with a spin orientation parallel to that of the nucleon spin when this is perpendicular to the incident beam. Transversity also manifests itself by a structure function that is a new aspect of the quark dynamics in the nucleon. In the years to come the COMPASS experiment will measure the transversity and bring information in this area that is essentially untouched experimentally.

The generalized parton distributions (GPD) allow an exploration of the three-dimensional structure of nucleons in terms of partons. The innovative aspect of these quantities is their sensitivity to correlations between partons, allowing for example, to connect them to the total angular momentum carried by the quarks or the gluons. Experimentally, the GPDs are accessible through exclusive hard reactions. Among these, the simplest process is deeply virtual Compton scattering (DVCS), $ep \rightarrow ep\gamma$. One of the first DVCS measurements was published by the CLAS collaboration at JLAB in 2002. Physicists from SPhN have contributed to the measurement of the spin asymmetry for the DVCS process at a beam energy of 4.2 GeV. New experiments are in preparation at JLAB using experimental equipment under construction at Saclay (Figure 5). The first goal of these exploratory measurements is to validate the theoretical connection between DVCS and GPDs.

In parallel with these experimental activities, the three theorists of SPhN have focused their activities on the structure of the nucleon and baryon resonances. Subjects that are particularly studied are the GPDs, the form-factors of the nucleon, and reactions for the electromagnetic production of photons and mesons in different kinematic regimes.

Today, there are good prospects for powerful electron facilities in the United States in particular at JLAB. It is therefore important to continue our investigations at JLAB in which, thanks to a future increase of the beam energy to 12 GeV, measurements of the GPDs will be carried out in a wider

![Figure 3. Large tracking stations are necessary to cover the solid angle of the ALICE dimuon spectrometer. The largest ones are visible on the picture, with station 3 located inside the dipole magnet and stations 4 and 5 downstream from it. They consist of cathode pad chambers arranged in slats on carbon fiber supports on both sides of the beam pipe and shielding. Station 3 is shown at its working position. Only the right halves of stations 4 and 5 are shown at their working positions. Dapnia/SPhN physicists and Dapnia technical divisions have been heavily involved in their design and prototype commissioning. Dapnia is responsible for building one fourth of them and for integrating all of them in the muon spectrometer.](image)
kinematic range from 2010 onward. In parallel, a team from SPhN is studying the possibility of measuring DVCS with the COMPASS spectrometer at CERN starting also in 2010 in a complementary kinematical region.

Physics for Nuclear Energy

In the years to come fast neutron reactors will enable the exploitation of the considerable resources offered by uranium $^{235}\text{U}$ as well as by an eventual $^{232}\text{Th}$ fuel cycle. Nevertheless, the

Figure 4. The COMPASS experiment at CERN has a broad physics program focused on the study of the spin structure of the nucleon and on hadron spectroscopy. The two-stage spectrometer is designed for high particle rates and high resolution tracking. The photo shows one of the Micromegas "doublets" consisting in two microstrip detectors oriented perpendicularly, with 1024 strips each covering a 40 $\times$ 40 cm$^2$ active area (top). Data taking has started in 2002, and will last at least until 2010. The first COMPASS preliminary result on the gluon polarization $\Delta G/G$, measured at a momentum fraction of the gluon $x_g=0.13$ has been obtained from high $p_T$ hadron pair data taken in 2002 and 2003. It is compared to HERMES and SMC published results and to theoretical predictions obtained from fits to polarized deep inelastic data (bottom).

Figure 5. The CLAS/DVCS experiment, to run in the spring of 2005 at Jefferson Lab, will investigate over a large kinematical domain the applicability of the new concept of Generalized Parton Distributions (GPD). A group of SPhN physicists is part of the leading effort to assemble and run this experiment. A forward photon calorimeter is being added in the middle of the CLAS spectrometer, and DAPNIA provides the laser monitoring for the 424 lead-tungstate crystals. The necessary magnetic shield for this calorimeter is a superconducting two-coil solenoid (this figure), entirely built at DAPNIA with an original cryogenic design, together with its controls and safety system. This is to date the largest equipment to be inserted within CLAS.
management of nuclear waste is an essential condition for the acceptance of nuclear energy by society. In order to progress in these areas and study new means of producing nuclear energy, the neutron production through spallation process should be carefully studied and precisely modeled. New sets of neutron induced cross-sections are also needed for many isotopes (especially those present in waste) under various types of reactor neutron fluxes. Our activities in this domain are focused along three major lines: spallation studies, neutron cross-section measurements, and application-oriented modeling.

The goal of the spallation studies is to achieve a complete understanding of spallation reactions with experiments covering a wide range of channels. An SPhN group is participating in spallation residue cross-section measurements at the relativistic heavy ion facility of GSI (Darmstadt, Germany). A new experimental program is now under development (SPALLADIN) with the aim of performing more exclusive spallation measurements by measuring spallation residues and evaporated light particles in coincidence in order to obtain information on the de-excitation stage of the reaction.

These experimental studies are complemented by theoretical development of high-energy spallation models (INCL4). These models, once validated with a wide set of experimental data, are incorporated in high-energy transport codes such as LAHET3 or MCNPX and used to evaluate quantities relevant to ADS design (Figure 6). It is foreseen that these studies will be continued at the planned R3B relativistic heavy ion facility at GSI and within the framework of the NUSTAR collaboration.

In recent years, high-resolution neutron-induced reaction cross-section measurements have gained much interest due to the development of new activities related to nuclear energy, such as the transmutation of nuclear waste, the thorium-based nuclear fuel cycle, and ADS. These new applications have triggered a renewed interest in neutron-nucleus reactions, in particular for isotopes and energy regions that are essential for the development and design of these concepts.

Figure 6. Mass distribution at several energies (top) and examples of isotopic distributions at 1 GeV (bottom) of spallation residues produced in p+Fe reactions measured using the reverse kinematics technique with the Fragment Separator at GSI (collaboration SPhN – GSI – IN2P3 – Santiago de Compostella University). The experimental results are compared with calculations using the Intra-nuclear Cascade model, INCL4, developed by the group in collaboration with the University of Liège, followed by two different de-excitation models: the solid line is obtained with a standard evaporation whereas the dashed line comes from a de-excitation code in which the production of light fragments originates from an asymmetrical fission mode competing with classical evaporation. These results have been used to compute the impurity production in an Accelerator-Driven System window. Recoil velocities have also been measured and allow assessing of damage due to atom displacements in such a window.
SPhN has been involved from the beginning in the construction of the new time-of-flight facility nToF at CERN. The strength of nToF lies in its very high instantaneous neutron flux making the nToF facility particularly suitable for measurements with a low signal-to-background ratio, as in the case of radioactive or low mass samples. SPhN is also involved in the neutron time-of-flight facility Gelina at Geel for carrying out both neutron capture and transmission measurements.

In addition to the energy-dependent cross-section measurements, integral neutron-induced cross-sections are investigated by SPhN groups within the Mini-Inca project. This project aims at determining experimentally the optimal conditions for the transmutation of minor actinides in high-intensity, highly thermalized neutron fluxes.

Furthermore, SPhN is involved in the measurement of neutron flux and actinide incineration rates inside the liquid lead-bismuth spallation target within the European MEGAPIE experiment (PSI, Switzerland). The MEGAPIE project is the first experimental demonstration of a 1MW liquid Pb-Bi spallation target coupled to a high intensity (1.5mA) proton accelerator. This experiment will take place in 2006.

In parallel with the aforementioned experimental activities, some fundamental and applied modeling activities have been developed. This expertise was developed to simulate and characterize neutron fluxes inside the experimental Mini-Inca channels. It is now applied to calculations of innovative nuclear systems for nuclear waste transmutation, intensive neutron sources based on spallation and photoneutron reactions, radioactive nuclear beam production scenarios, characterization of nuclear waste barrels, production of neutron-rich fission fragments, and so on, in close cooperation with the LANL (U.S.).

These modeling tools are based on a Monte Carlo technique allowing realistic geometry and material

Figure 7. The n_TOF collaboration has recently built and exploited a new neutron time-of-flight facility at CERN in the frame of a shared cost RTD action of the Fifth EU Framework Program. Since the final commissioning, a scientific program of measurements of neutron capture and fission cross-sections of actinides, long-lived fission fragments and other isotopes relevant for nuclear technology and nuclear astrophysics, has been scheduled in a first phase from 2001 to 2004. The figure shows an example of the count rate spectrum of the $^{232}$Th(n,$\gamma$) capture cross-section experiment at n_TOF at CERN, measured with neutron insensitive deuterated benzene gamma-ray detectors. The program for a second phase of measurements at CERN is currently in preparation.
This expertise led us to undertake modeling related to the decommissioning of nuclear installations such as particle accelerators and research or industrial nuclear reactors, in collaboration with DAPNIA/SDA. We expect these activities to be pursued in the future within the framework of collaboration with the valorisation DAPNIA/cell. Finally, among emerging activities we would like to quote participation in Monte Carlo simulations of emission tomography for medical diagnostic and treatment purposes.

The Service de Physique Nucléaire is part of the national basic research community and contributes to the excellence of French research while actively participating in the fundamental missions of the Commissariat à l'énergie atomique.

NICOLAS ALAMANOS
Saclay

laboratory portrait

specifications in 3-D. When available, the evaluated data libraries are used for multiparticle–nucleus interactions and transport calculations. Otherwise recent nuclear models are applied to simulate different processes of interest including time-dependent evolution of nuclear fuel and/or irradiation/production targets. These activities serve as direct evidence of the link between knowledge of fundamental nuclear physics and society-related problems.
A Relativistic Symmetry in Nuclei

Q1 AU: what is?
A Relativistic Symmetry in Nuclei

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Introduction

More than thirty years ago it was observed that certain quantum energy levels in atomic nuclei were almost degenerate in energy [1]. The states that are almost degenerate (quasi-degenerate) have different radial quantum numbers and different orbital angular momenta, features that made the reason for their degeneracy difficult to penetrate.

The dynamics of neutrons and protons in nuclei have been successfully treated non-relativistically. Therefore it has come as a surprise that this quasi-degeneracy of quantum states in heavy nuclei, which has eluded understanding for about thirty years, can be explained by a relativistic symmetry [2].

The Nuclear Shell Model

Atomic nuclei are well described by nucleons moving in a non-relativistic mean field with residual interactions that induce correlations between the nucleons. The dynamics of the nucleons in the orbits are described by the non-relativistic Schrödinger equation. For spherical nuclei the quantum numbers of the orbits in the mean field are the radial quantum number, n, the orbital angular momentum, l, and the total angular momentum, j, which is the sum of the orbital angular momentum and the spin; (n, l, j) for short. The orbits that are quasi-degenerate in energy are (1, 0, 1/2) and (0, 2, 3/2), (1, 1, 3/2) and (0, 3, 5/2), and so on. That is, the orbit with (n, l, j = l + 1/2) will be quasi-degenerate with the orbit (n − 1, l + 2, j = l + 3/2); that is the radial quantum numbers will differ by one unit, the orbital angular momenta will differ by two units, and the total angular momenta by one unit.

For deformed nuclei the orbits that are quasi-degenerate have angular momentum projection along the symmetry axis differing by two units and total angular momentum projection differing by one unit.

The Dirac Hamiltonian

The Dirac equation, not the Schrödinger equation, must be used to describe the relativistic dynamics of nucleons moving in a relativistic mean field. In the limit that the relativistic mean field is small compared to the kinetic energy, the non-relativistic limit, then the Schrödinger equation will be a good approximation to the Dirac equation.

The Dirac equation has positive energy eigenfunctions and negative energy eigenfunctions. The former are the eigenfunctions of the particles and the latter are the eigenfunctions of the anti-particles. A Dirac eigenfunction will then have twice as many components as a Schrödinger eigenfunction. In the non-relativistic limit, the “upper” component of the positive energy eigenfunctions will become the Schrödinger eigenfunctions for the particles and the “lower” component will become vanishingly small, whereas the “lower” component of the negative energy eigenfunctions will become the Schrödinger eigenfunctions for the anti-particles and the “upper” component will become vanishingly small.

Likewise, in the Dirac equation two types of potentials are possible, one a relativistic scalar and one a relativistic vector. The sum of the two potentials dominate the dynamics of the particles whereas the difference of the two dominate the dynamics of the anti-particles.

Symmetries of the Dirac Hamiltonian

When the scalar potential and vector potential are equal the Dirac Hamiltonian has spin symmetry. This means that the eigenfunctions that differ in the orientation of the spin will be degenerate in energy. That is, the orbits (n, l, j = l + 1/2) and (n, l, j = l − 1/2) will have the same energy. These states are spin doublets because the energy does not depend on the orientation of the spin. This symmetry occurs in hadrons [3].

When the scalar potential is equal to the vector potential, but opposite in sign, there is another symmetry of the Dirac equation. This symmetry is called pseudospin symmetry. The states that are degenerate have exactly the radial quantum numbers and orbital angular momenta of the quasi-degenerate states that have been observed in nuclei and are pseudospin doublets.

Relativistic Mean Field

Relativistic models of nuclei include nuclear field theories with nucleons interacting by the exchange of mesons on the one hand and nucleons interacting with relativistic interactions.
These models are difficult to solve exactly but have been
solved in the relativistic mean field approximation, which
reduces to a Dirac Hamiltonian with the scalar and vector
potentials determined self-consistently [4]. The resulting
scalar and vector potentials are opposite in sign and
approximately equal in magnitude. Thus the symmetry,
which was observed in the nuclear states more than thirty
years ago, is pseudospin symmetry, a symmetry of the
Dirac Hamiltonian.

Predictions of Pseudospin Symmetry

Amplitudes

One of the predictions of this pseudospin symmetry is
that the spatial amplitudes of the lower components for the
two states in the degenerate doublets should be equal in mag-
nitude. We have tested this condition by examining the lower
amplitudes of the Dirac eigenfunctions determined in relativ-
istic mean field calculations of nuclear spectra using realistic
vector and scalar potentials [5]. In Figure 1 we show an
example of the amplitudes of the lower components of two
states of a pseudospin doublet in in the spherical nucleus
$^{208}$Pb. in Figure 1a is the upper amplitude, $g(r)$, for the ($n=1,
l=0, j=1/2$) state (solid line) and the ($n=0, l=2, j=3/2$) state
(dashed line). These radial amplitudes have very different in
shapes. However, the lower amplitudes, $f(r)$, are almost iden-
tical as seen in Figure 1b. In Figure 1c is the upper ampli-
tude, $g(r)$, for the ($n=2, l=0, j=1/2$) state (solid line) and the
($n=1, l=2, j=3/2$) state (dashed line). Again these radial
amplitudes have very different shapes. However, the lower
amplitudes, $f(r)$, are almost identical, as seen in Figure 1d. As
the radial quantum number increases, the lower amplitudes
become more similar, implying that pseudospin conservation
improves as the binding energy decreases.

Pseudospin symmetry also imposes conditions on the upper
amplitudes but these are more complicated, involving differen-
tial equations between the amplitudes. However, these condi-
tions are approximately satisfied as well and improve as the
binding energy decreases [6] just like the lower amplitudes.

A survey of other states in both deformed and spherical
nuclei for pseudospin symmetry in both upper and lower
components show that pseudospin symmetry is approximately
conserved and the conservation increases as the binding
energy decreases [7].

Figure 1. The upper amplitudes, $g(r)$, and lower amplitudes, $f(r)$, versus the radius $r$. 
Magnetic Dipole and Gamow Teller Transitions

Magnetic dipole transitions between pseudospin doublets are forbidden non-relativistically because the states in the doublets have angular momentum differing by two units and the dipole can only change the angular momentum by at most one unit. However, these transitions are allowed relativistically.

If pseudospin symmetry is conserved, then, if the magnetic moment of the states in the doublet is known, the magnetic dipole transition between the pseudospin doublets can be determined [8]. For example, using the magnetic moment of the ground state of $^{39}$Ca, the predicted magnetic dipole transition agrees with the measured transition within experimental error. A global analysis of such transitions for many nuclei shows that these predictions are approximately valid [9]. Similar relations hold for Gamow Teller transitions in beta decay as well.

Nucleon-Nucleus Scattering

The elastic scattering of medium energy nucleons from nuclei can be described successfully with a relativistic optical model with complex scalar and vector potentials. The scalar and vector potentials determined by fitting the scattering data are approximately equal in magnitude but different in sign even though they are complex [10].

The scattering amplitude consists of two parts, one independent of pseudospin symmetry and one pseudospin dependent. The pseudospin dependent amplitude has been extracted from the measured spin polarization and the spin rotation [11,12]. For the scattering angles measured the pseudospin dependent amplitude is only 10% of the pseudospin independent amplitude. For lower energy nucleons, however, the pseudospin breaking increases [13].

Antinucleon-Nucleus Scattering

A nucleon changes into an antinucleon under charge conjugation. Under charge conjugation the scalar potential remains unchanged but the vector potential changes sign. Thus, an antinucleon in a nuclear environment will experience vector and scalar potentials that are approximately equal. This implies spin symmetry. Indeed, spin polarization measured in antinucleon nucleus scattering is consistent with zero, implying spin symmetry [14].

Fundamental Theory of the Strong Interactions and Pseudospin Symmetry

Quantum Chromodynamics (QCD), the fundamental theory of the strong interactions, predicts that the vector and scalar potentials in nuclei are almost equal in magnitude and opposite in sign [15], which is consistent with approximate pseudospin symmetry. The difference in sign comes from the fact that the quark condensate of the vacuum is negative.

Future Study

This connection with QCD suggests that there may exist a more basic rationale for pseudospin symmetry in nuclei based on the interaction between quarks that needs to be explored. For example, one question is “Why is pseudospin symmetry valid for nuclei, whereas spin symmetry is valid for hadrons?”


JOSEPH N. GINOCCHIO
Exploding Stars, Neutrinos, and Nucleosynthesis

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Exploding Stars, Neutrinos, and Nucleosynthesis

GAIL MCLAUGHLIN

Exploding Stars

Supernovae are some of the most violent, energetic events that occur in the universe. The most recent supernova in our Galaxy that could be seen from earth was Cassiopeia A, which occurred about 1680. This supernova was the explosion that ended the life of a massive star, also called a core collapse supernovae. Observationally, supernovae are divided into two main types, Type I and II, where the classification is based on their spectral features. Type I supernovae do not have hydrogen lines in their spectra whereas Type II supernovae do. Type II supernovae are always core collapse supernovae, but only some of Type I supernovae are.

Type Ia and core collapse supernovae are very different objects. A Type Ia supernovae occurs when a white dwarf star, such as a carbon–oxygen white dwarf, is in a binary system with an ordinary star. The white dwarf star slowly accretes material from the outer envelope of its companion. Once sufficient material has been accreted so that the density or temperature on the white dwarf becomes quite high, for example, densities of $2 \times 10^9$ g/cc, a runaway nuclear fusion reaction results. The energy released from the fusion process powers an explosion. Type Ia supernovae are considered to have nearly constant luminosity and are therefore used as “standard candles,” meaning that their apparent luminosity is a way to judge their distance. Comparing the inferred distance with the redshift is one of the ways that has been used to measure (and discover!) the acceleration of the universe.

A Type II supernova comes from the explosion that ends the life of a star that has a mass of around ten to thirty times the mass of our sun. Throughout most of their lives, stars shine by burning hydrogen to helium, as is happening right now in the sun. The energy released from the binding of free nucleons into helium provides the pressure that supports the star against gravity. After the sun has exhausted the majority of its hydrogen supply, it will burn helium into carbon and oxygen. The gravitational pressure will not be sufficient to compress the star to temperatures required to burn past oxygen and so the sun will end its life as a carbon–oxygen white dwarf.

A more massive star will continue to burn beyond carbon and oxygen and create heavier nuclei all the way to iron, which is the most tightly bound element. An “onion ring” structure develops in the star with hydrogen as the outer ring, then helium and the heavier elements, and iron at the core. The iron core is initially supported by degenerate electron pressure, as is the case for a white dwarf. As the core reaches higher densities electron capture sets in and the core becomes unstable. The inner core quickly collapses to nuclear density. At this point matter becomes very incompressible and the core rebounds. When infalling material hits outgoing material a shock wave is formed, which begins to propagate outward. Up to this point, the explosion has been successfully modeled on large computers. However, the details of how the shock ejects the outer layers of the star have never been convincingly demonstrated.

This should not come as a surprise. The problem of theoretically modeling the explosion is difficult because it combines many areas of physics, such as general relativity, hydrodynamics, neutrino, and nuclear physics. Also, the energy balance is very delicate. Neutrinos carry away about 99% of the binding energy of the iron core, about $10^{53}$ erg. Only a small fraction of the total energy goes into the kinetic energy of the shock. Finally, constructing detailed models is computationally very intensive, and the effort required for three-dimensional models with sufficient granularity is still prohibitively large. All of this does not imply, however, that we cannot study other aspects of the supernova. In the following we shall see that there are many phenomena related to supernovae about which we can learn even without yet having a definitive theoretical model of the explosion mechanism.

Before we come to this, we would like to complete our brief tour of exploding stars. Type Ib and Ic supernovae are also without hydrogen lines, but these are not thermonuclear detonations off the surfaces of white dwarfs as one might expect from the name. Instead, Type Ib and Ic are core-collapse supernovae, similar to the Type II supernovae described earlier, but distinguished by the fact that the progenitor lost its hydrogen envelope (Ib) or hydrogen and helium envelope (Ic) prior to collapse.

Gamma ray bursts, first discovered more than thirty years ago, are intense bursts of gamma rays. The astrophysical origin of these bursts was largely mysterious up until...
very recently. Over the last few years the situation is evolving very rapidly, as significant amounts of data from satellites and ground based telescopes are being gathered. Gamma ray bursts can be classified into long and short duration bursts. In the 1990s data was taken on the long duration bursts, and it was discovered that they have counterparts in the X-ray, optical and radio parts of the spectra, the "afterglow," which goes on for days or even months (in the case of radio emission) after the initial gamma ray burst. More recently, a few cases were discovered that show a "bump" in the light curve of the afterglow. This bump can be fit to a traditional core-collapse supernovae light curve, that is, the kind that is driven by the beta decays of nickel and cobalt. In a few cases spectra have been taken and the spectra look remarkably like those seen in Type Ib or Ic data. The clear suggestion is that gamma ray bursts come from some sort of unusual core collapse supernova event.

Nuclear physics plays many roles in all of these events. It is nuclear reactions that produce the energy that powers the explosion in Type Ia supernovae. It is the nuclear equation of state that determines the point at which the collapse is halted and the shock wave is formed in core collapse supernovae. It is the neutrino scattering reactions that may provide the necessary energy to keep the shock wave moving, once it has been produced. Furthermore, all of these types of supernovae produce unique nucleosynthesis products that make important contributions to the amount and type of elements that exist in the solar system today.

Neutrinos are an essential component for understanding core collapse supernovae for many reasons, the most obvious being that they carry the vast majority of the energy. The core formed by the collapse of the star, called a proto-neutron star, is so hot (\(100\text{MeV}\)) and dense (\(10^{14}\text{g/cm}^3\)), that not only are the photons trapped but the neutrinos are as well. Neutrinos are produced thermally and are emitted, about \(10^{57}\) of them, in all three flavors, electron, mu, and tau, as well as their anti-particles. Because neutrinos interact only by the weak interactions, they decouple at the surface of the core where the temperature is around 10 MeV–25 MeV and exit the star in the first tens of seconds.

In contrast, photons do not escape for many hours. Not only do the neutrinos emerge first but in most cases they may be all that we can detect here on earth. For a supernova in our galaxy the photons may never be seen at all, because most of our Galaxy is obscured by dust. This is the reason why, although estimates of the Galactic core collapse supernova rate are around every 50 years or so, the last supernova observed on earth occurred more than 300 years ago.

Neutrinos from a core collapse supernovae were detected only once, from Supernova 1987a in the Large Magellanic Cloud, by the Kamiokande and IMB detectors. In the mean time, much larger neutrino detectors are on-line for detection.
that could potentially record thousands of events from a galactic supernova. Although supernovae are rare, such a detection is much anticipated. As discussed earlier, neutrinos provide a window into the center of the supernova. Neutrinos will scatter last at the surface of the core, and as a result their spectrum reflects the conditions at this point.

**Nucleosynthesis**

As well as being a unique source of neutrinos, supernovae are also the site of unique types of element synthesis. Explosive burning in core-collapse supernovae occurs as nucleons and nuclei are fused together as the shock wave from the explosion passes through. This results in a considerable production of Nickel-56, which beta decays first to Cobalt-56 and then to Iron-56. After the beta decay the daughter nucleus decays by emitting a gamma ray. The decay photon is thermalized as it scatters off surrounding material and drives the supernova light curve. In fact, it is the beta decay lifetimes of these nuclei that determine the timescale of the observed light curve. The iron produced in explosive burning also contributes significantly to the galactic inventory of this element.

In addition to explosive burning, there are other types of nucleosynthesis that may occur in core-collapse supernovae, such as rapid neutron capture (or r-process) synthesis. “Rapid” means that the time scale for neutron capture is short compared to the time scale for beta decay. The r-process is responsible for almost half the heavy elements (those with mass number A > 100), including the transuranic elements such as Uranium and Thorium. Although the mechanism for producing these elements has been known since the late 1950s, the astrophysical site remains a mystery. Recent observational results of low metallicity halo stars show that the abundance pattern for r-process elements in very old stars is very similar to that observed in our own solar system. This suggests that the same type of event is producing the same elemental pattern over and over again.

The neutrino-driven wind of the core supernova is a seductively simple possibility for producing these elements. Supernovae occur on the right time scale in order to account for the amount of r-process material present in the galaxy. Also, core collapse supernovae begin occurring relatively early on, explaining the presence of r-process elements in old stars. The neutrino-driven wind occurs after the first tenths of seconds when the shock has moved far out in the star. The neutrinos continue to impart a small amount of their energy to the material on the surface of the proto-neutron star and push these free neutrons and protons out in a wind. The prospects for making the r-process depend on the relative number of free neutrons and protons, which in turn depends on the relative rate of electron neutrino and anti-neutrino capture on free nucleons in this wind. The electron anti-neutrinos, having decoupled slightly deeper in the core than the electron neutrinos, have slightly higher energy than the neutrinos. The balance of the charged current neutrino interactions therefore drives the material neutron rich and creates a potentially viable environment for the r-process.

Detailed calculations have shown that the neutrino-driven wind comes very close to producing the r-process elements. One of the reasons that this environment is not completely successful is again related to the neutrinos. An important early stage of the r-process involves alpha particles and neutrons. A successful r-process requires many neutrons per alpha particle. However, if the neutrino flux is large charged current reactions convert neutrons to protons that immediately combine with neutrons to form more alpha particles, and the number of neutrons per seed nucleus becomes too small. We must find either find physics missing from our calculation of the wind, or look to another environment.
Exotic Supernovae

There have been hints that there is not just one way in which a core collapse supernovae explodes but instead a range of possibilities. As mentioned earlier, some of these bursts have spectra that look similar to Type Ib and Ic supernovae. What makes an “ordinary” core collapse supernovae and what makes a gamma ray burst? Theorists have speculated that it is the degree of rotation of the presupernova star. Stars with too much rotation do not collapse and bounce efficiently enough to produce a robust shock. Instead the core collapses into a black hole, surrounded by an accretion disk. Neutrinos are emitted copiously off of the surface of this disk. Depending on the accretion rate and the spin parameter of the black hole, the neutrinos may or may not be trapped in the inner portion of the disk. In either case, only electron type neutrinos and antineutrinos are produced because the temperatures are lower than they are in the core of the proto-neutron star in the regular supernova. The geometry of the disk provides maximum opportunity for neutrino-anti-neutrino annihilation. Heating from neutrino-anti-neutrino annihilation, combined with electromagnetic extraction of energy from the rotating black hole may be responsible for powering the burst. The burst itself consists of ultra-relativistic ejecta emitted directly above the black hole. Models for this process are currently being developed and it will likely prove even more challenging than modeling the traditional core collapse supernova environment due to the more complicated geometry and the stronger effects of general relativity.

The neutrinos that are emitted from the disk have average energies on the order of a few MeV. In addition to these, very high-energy neutrinos of around $10^{15}$ eV can be produced by photo-pion reactions. High energy protons can scatter off the radiation field of the source and produce pions that decay into muons and neutrinos. Because gamma ray bursts are rare, we are unlikely to observe one in our Galaxy, but very high-energy neutrinos can be detected even if they originate from objects well beyond our Galaxy. It may be possible to observe these neutrinos with kilometer cubed detectors such as Ice Cube and Amanda.

This new type of core collapse supernova will produce a unique set of nucleosynthesis products. Although these events are fairly rare, perhaps $10^{-5}$ per year per galaxy as opposed to $10^{-2}$ per year per galaxy for typical supernovae, they can still contribute significantly to cosmic element abundances. What elements are produced in gamma ray bursts? It is difficult to know for certain until more complete hydrodynamic models exist. However, some things we can guess. In order to account for the “bumps” in the the light curve that look like standard supernovae, one needs nickel, on the order of half a solar mass. So some nickel must be synthesized in the burst. Does it occur from explosive burning as in the standard core collapse supernovae, or does it come from material ejected from an accretion disk, perhaps in a wind? The material in the disk is hot enough so that it is dissociated into free neutrons and protons. Not all the material will be accreted into the black hole, some will be ejected and the free neutrons and protons will recombine into nuclei. If the material is sufficiently neutron rich, as would be the case for very high accretion rates, we may find the r-process. If the material is roughly 50% neutrons and 50% protons, considerable nickel will be produced, but perhaps also an unusual smattering of other rare nuclei.

Outlook

In summary, the subject of supernovae is a unique combination of many different branches of physics, and there are many different ways in which we can probe their inner workings. Traditional astronomy uses photons of all wavelengths and spectra can be used to probe nucleosynthesis products. We can now supplement this information by measuring neutrinos from future galactic supernovae. Theoretically there is much to learn by combining nuclear reactions, neutrino scattering, general relativity, and much more. In addition to that we are discovering whole new types of events that are also associated with supernovae. Whatever the future of supernova research brings, it promises to be an exciting time.

References

High-Resolution Gamma-Ray Spectroscopy at TRIUMF-ISAC

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High-Resolution Gamma-Ray Spectroscopy at TRIUMF-ISAC

Introduction

It is no accident that the rapid technical evolution of radioactive beam facilities has coincided with challenges to the standard models of nuclear structure and fundamental interactions. In nuclear structure, the shell model is a de facto standard model. The properties and systematics of nuclei near stability are well understood in terms of the magic nucleon numbers at shell closures. However, when confronted with experimental data on increasingly exotic nuclei, the model fails. The near-stability magic nucleon numbers disappear, and new ones emerge [1]. This is evidenced for example by the energies and γ transition rates of excited states. These excitations may be probed by reactions induced with accelerated radioactive beams, or by a parent β decay. At the same time, high production yields for selected isotopes allows for very high precision measurements of specific decay processes. Because β decay is a nuclear manifestation of the weak interaction, high precision measurements of nuclear β decay provide a strict test of fundamental symmetries [2].

Gamma-ray spectroscopy has long been a cornerstone of decay and in-beam nuclear physics experiments. For these measurements, high-purity germanium (HPGe) detectors deliver the necessary energy resolution and efficiency. Signal-to-noise, that is, peak-to-total ratios, can be further improved by surrounding the HPGe with inorganic-scintillator escape suppression shields that veto events with only partial photon energy deposition. Gamma-ray spectroscopy is most powerful in multi-γ or γ-particle coincidences to isolate specific decay branches from otherwise overwhelming backgrounds.

The Tri-University Meson Facility (TRIUMF) cyclotron can deliver up to 100 µA 500 MeV proton beam to the Isotope Separator and Accelerator (ISAC), a modular high-power ISOL-type radionuclide production and mass separation system. Activities are ionized, extracted, and delivered to the low-energy area for decay experiments, or injected into radio-frequency quadrupole and drift-tube linear accelerators (DTLs) for delivery to higher-energy experimental stations. ISAC-I accelerates ions with mass-to-charge A/q<30 up to 1.8 MeV/u primarily for nuclear astrophysics experiments. When completed in 2007, the charge state booster and superconducting DTLs of ISAC-II will deliver beams with masses up to A ~ 150 at energies up to 6.5 MeV/u for near- or above-barrier nuclear physics experiments [3].

The 8π spectrometer

The HPGe detector array now known as the 8π spectrometer began as a joint venture between Université de Montréal, McMaster University and Atomic Energy of Canada Limited (AECL). It was named after an initial conceptual design with a 4π inner calorimeter and a 4π suppression scheme. The 8π was installed in 1985 at AECL Chalk River’s Tandem Accelerator Superconducting Cyclotron (TASCC) facility, where it was used primarily for pioneering work in high-spin nuclear structure. In 1997, the 8π moved to Lawrence Berkeley National Laboratory, and in 2000 it was repatriated to the ISAC low-energy beam area [4].

The 8π (Figure 1) has been reconfigured for high-precision β-decay measurements.

Figure 1. The 8π, downstream half of SCEPTAR, and tape system.
facilities and methods

measurements. The inner calorimeter and front suppressor shields have been removed, and the 20 HPGe and bismuth germanate (BGO) suppressors have been moved forward. Hevilit collimators prevent the BGO suppressors from viewing \( \gamma \) rays from the HPGe focus. Delrin absorbers stop \( \beta \) particles from entering the HPGe while minimizing bremsstrahlung.

Associated Systems

SCEPTAR, the Scintillating Electron-Positron Tagging Array, consists of twenty thin plastic scintillators (\( \Delta E \) of 500 keV for minimum ionizing electrons) in vacuum subtending 80\% of the solid angle around the 8\( \pi \) focus (Figure 2). Each HPGe is co-linear to the focus of the array with a unique SCEPTAR scintillator.

The tape system (Figure 1) is a continuous loop up to 150 m long moving at up to 1.3 m/s. It is intended to remove long-lived activities (daughters or beam contaminants) out of the focus of the detectors and behind a lead wall. With SCEPTAR, the tape system, and Delrin absorbers installed, the 8\( \pi \) has a \( \gamma \)-ray photopeak efficiency of 1.0\% at 1.332 MeV, and a peak-to-total ratio of 41\% for \( ^{60}\text{Co} \).

The upstream 10 detectors of SCEPTAR may be replaced with the Pentagonal Array Conversion Electron Spectrometer (PACES), up to five cryogenically cooled 5 mm thick Si(Li) detectors subtending 6\% solid angle (Figure 2) [5]. PACES has recently been used in an in-beam experiment elucidating low-spin \( ^{156}\text{Dy} \) structures populated by \( ^{156}\text{Ho} \) \( \beta \) decay [6].

Science Highlights

The High Precision Program: The 8\( \pi \) and its new associated equipment are intended for high precision (~0.05\%) measurements of lifetimes and branching ratios in superallowed \( 0^{+}\rightarrow 0^{+} \) Fermi \( \beta \) decays [2,4]. These measurements test the Conserved Vector Current hypothesis and the unitarity of the CKM quark-mixing matrix. High precision \( \gamma \) and conversion electron measurements are needed not only for branching ratios, but in selected cases, also for measuring lifetimes. For example, \( ^{34}\text{Ar} \) and its daughter \( ^{34}\text{Cl} \) both \( \beta \) decay and have nearly the same half-lives, so it is impossible to disentangle their \( \beta \) decay curves and measure the \( ^{34}\text{Ar} \) half-life with the necessary precision. However, \( ^{34}\text{Ar} \) also emits \( \gamma \) rays following the \( \beta \) decay, so \( \gamma \)-ray counting is promising for measuring the \( ^{34}\text{Ar} \) half-life with the needed precision. The technique has been investigated in detail with \( ^{26}\text{Na} \) decay, to compare traditional \( \beta \) counting with \( \gamma \) counting. The first measurement in this program has been the half-life of \( ^{186}\text{Ne} \), yielding a measurement with a statistical uncertainty of ~0.1\% [7]. Measurements on other superallowed Fermi \( \beta \)-decay nuclei will continue as ISAC beams become available.

\( ^{176}\text{Lu} \): The first measurement with the 8\( \pi \) at ISAC was the half-life of the geochronometer \( ^{176}\text{Lu} \). By counting \( \gamma\gamma \) coincidences with 8\( \pi \) HPGe detectors, several sources of systematic uncertainty were eliminated. A half-life of \( ^{176}\text{Lu} \) of 40.3(3) billion years was reported. [8].

High-K isomers are a prime example of the interplay between collective and single-particle degrees of freedom in nuclear systems [9]. The 8\( \pi \) was first to observe the M4 and E5 \( \gamma \) rays de-exciting a high-K isomer, namely the 31-year \( ^{178}\text{Hf} \) isomer. These are \( \sim 10^{-4} \) branches, and establish a reduced hindrance factor of \( \sim 100 \) for all observed K-isomer decay branches of this isomer [10]. The 8\( \pi \) also has been used in a campaign to identify new high-K isomers in ISAC beams [11]. In the first experiment, a new isomer in \( ^{174}\text{Tm} \) with a half-life of 2.3 s has been identified [12]. The tape system was critical for removing long-lived daughters and beam isobars from the focus of the HPGe detectors.

\( ^{11}\text{Li} \): The halo nucleus \( ^{11}\text{Li} \) and its daughter \( ^{11}\text{Be} \) are classic examples of novel nuclear behavior at the extremes of weakly bound nuclei. However, despite numerous experimental studies,
discrepancies persist in γ-ray intensities following β decay and in the level scheme for neutron-unbound 11Be states ([13–15] and references therein).

In one of the first 8π in-beam experiments, 500 atoms/s of 11Li were deposited on an aluminum foil at the array focus. The lineshapes for 10Be γ rays (Figure 3) are Doppler broadened due to the recoil of the residue following 11Be* neutron emission. These lineshapes depend on the energies, spins, branching ratios, and lifetimes of states in the β-n-γ decay chain. The data were analyzed by comparison with Monte-Carlo simulations of the decay of 11Li and of the stopping of the 10Be recoil in aluminum. Lifetimes of states in 10Be were measured, and limits on n-γ correlation parameters were consistent with spins allowed in the observed β-n-γ cascades. The data also confirmed the existence of an 8.03 MeV state in 11Be first postulated in Ref. [13]. The data show clear evidence that the 8.81 MeV state decays by neutron emission to the 10Be 2− and 2+ states, but no evidence for decay to the 1+ state. This is consistent with a spin and parity of 5/2− for the 8.81 MeV state in 11Be, raising questions about the structure of this state and the possible halo-neutron survival through a core decay process [14]. However, like all previous measurements in 11Li, discrepancies remain; Fynbo et al [15] did not report any evidence for the 8.03 MeV state in 11Be. The experiment has recently been repeated with the 8π and SCEPTAR, generating a data set ~20 times larger. Along with resolving outstanding intensity and feeding discrepancies, with higher statistics, n-γ angular correlation parameters can be constrained for spin assignments. Also, by vetoing co-linear β-γ coincidences, bremsstrahlung continuum is suppressed; for example, the overall continuum background near the 219keV 10Be line is reduced by 40% [16].

TIGRESS

Accelerated radioactive beams can be used to access excited states in exotic nuclei through mechanisms such as inelastic scattering, particle transfer, and fusion-evaporation. Each has its own role for probing collective or single-particle modes over ranges of excitation energy and angular momentum. However, experiments with radioactive beams face additional challenges of limited beam intensity, isobaric contamination, and Doppler shift of γ rays from reaction products. HPGe outer-contact segmentation and digital signal processing provide high effective granularity for measuring the laboratory-frame γ emission angle. The arrays become compact and offer a cost-effective solution for high efficiency without excessive Doppler correction uncertainty. Large arrays of high effective-granularity HPGe detectors have been installed at many of the premier radioactive beam facilities, including CLARION at Oak Ridge, SeGA at Michigan State, Miniball at REX-ISOLDE, and EXOGAM at GANIL [4]. The 8π’s small and unsegmented HPGe detectors are best suited to their current role in decay spectroscopy. In-beam spectroscopy, with the high-energy, high-mass beams from ISAC-II, requires a new array.

The TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer (TIGRESS) will comprise 12 units of HPGe four-crystal “clover” detectors,
facilities and methods

(Figure 4), with back and side suppressors mounted to the cryostat. These units are arranged in a rhombicuboctahedral geometry and can be inserted to a close-packed configuration for a high photopeak efficiency of ~12% for 1 MeV photons, or can be withdrawn for insertion of front-suppressor BGO plates in a high-peak-to-total configuration. In both cases a spherical volume with a radius of 11 cm is available for auxiliary detectors and target chambers. Each of the >38% relative efficiency HPGe crystal outer contacts is segmented eightfold, into four quadrants and with a lateral depth segmentation, for sub-segment effective granularity through waveform analysis. All signals will be digitized with custom-built readout and triggering systems developed in parallel with those for another major TRIUMF initiative, KOPIO [17]. The support frame will allow rapid redeployment from the high-efficiency to high-peak-to-total configurations in one working day with no re-cabling or detector removal. First Coulomb excitation experiments with four units are expected in mid-2006, with completion of the array in 2009 for fusion-evaporation and particle-transfer reactions in concert with auxiliary charged particle and recoil detectors.

A prototype HPGe detector unit was shown to meet expectations. In standard tests with 1332 keV gamma rays from $^{60}$Co sources, all four AC-coupled center contact full-volume signals gave better than 2.3 keV energy resolution, and the efficiency of the full unit was 215% in addback mode. All outer contacts, instrumented with room temperature FETs, delivered <3.2 keV resolution [18]. The single-interaction position sensitivity, as defined by Vetter et al. [19], is 0.44 mm [20]. A set of prototype suppressor shields yielded peak-to-total ratios of 35% and 50% in the high-efficiency configuration and high peak-to-total configurations. [21].

Summary

High energy-resolution $\gamma$-ray spectrometry is a powerful and versatile technique in nuclear physics research. At ISAC-I, the $8\pi$ and associated tape system, SCEPTAR and PACES have been installed for high-precision $\beta$-decay measurements, and have already demonstrated their broad applicability to outstanding nuclear physics questions. The TIGRESS array will provide the high efficiency and high effective granularity needed to meet the challenges of nuclear structure experiments with accelerated radioactive beams from ISAC-II.

Acknowledgments

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Radioactive Ion Beam Facility in Brazil (RIBRAS)

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Nuclear physics has been going through a major evolution over the last decade with the possibility of producing secondary beams of nuclei far from the stability line (exotic nuclei). Many new facilities have been put to work in order to investigate nuclei at extreme conditions of density, temperature, and with a high number of protons or neutrons. In particular, the possibility of using exotic nuclear beams has opened an exciting field of investigation in nuclear physics with strong implications in nuclear astrophysics.

The Pelletron Laboratory of the University of São Paulo installed the first South American Radioactive Ion beams device (RIBRAS) [1–3]. This facility extends the capabilities of the original Pelletron accelerator by producing secondary beams of unstable nuclei.

A picture of this facility is shown in Figure 1.

The most important components in this facility are the two new superconducting solenoids. The solenoids have 6.5T maximum central field (5T.m axial field integral) and a 30 cm clear warm bore, which corresponds to an angular acceptance in the range of $15 \degree \geq \theta \geq 2 \degree$.

The solenoids were manufactured by Cryomagnetics INC (USA) and were designed to operate in connection with the Linac post-accelerator of maximum energy of 10 AMeV, presently under construction. With the LINAC, the energy of the primary beam will be about 2–3 times larger than the maximum energy of the present Pelletron Tandem of 8 MV terminal voltage (3–5 AMeV).

The presence of the two magnets is very important to produce pure secondary beams. The first solenoid makes an in-flight selection of the reaction products emerging from the primary target at forward angles. As the first magnet transmits all ions with the same magnetic rigidity $(B\rho)^2 = mE/q^2$ the purity of the radioactive secondary beam in the mid-scattering chamber can be rather poor. With two solenoids, it is possible to use differential energy loss in a degrader foil, located at the crossover point between the magnets. This degrader foil will allow the second solenoid to select the ions of interest by moving the contaminant ions out of its bandpass. Time of flight technique using a pulsed primary beam is also very useful to identify nuclei of interest in the secondary beam. The buncher system to pulse the primary beam of the Pelletron accelerator is presently being installed.

An additional future possibility for the two solenoid system is the production of tertiary beams using a secondary target in the mid-scattering chamber. The second solenoid can be tuned to select a different magnetic rigidity producing low intensity (1–100/s) tertiary beams like $^6\text{Li}$, $^4\text{He}$ [4,5]. This is, in principle, possible with secondary beams of $10^7$ p/s and assuming a typical conversion efficiency of $10^{-5}$ for the secondary reaction.

The two solenoids are presently installed in the 45B Pelletron beam
facilities and methods

It should be noted that setting up the double solenoid system prior to the completion of the LINAC post-accelerator is an important issue. This makes possible to begin experiments with a facility that is similar to the TWINSOL system at Notre Dame University [5]. This first stage with the Pelletron primary beam of \( ^7\) Li of 3–5 AMeV and \( 1 \mu\) A maximum current, allows the production of secondary beams such as \( ^7\) Be, \( ^3\) B, \( ^6\) Li, \( ^4\) He with intensities around \( 10^4 \) to \( 10^6 \) particles per second. With these intensities one can perform measurements of elastic scattering angular distributions and studies of the interaction potential of systems involving exotic projectiles allowing the investigation of phenomena such as proton and neutron halo in nuclei.

Probably the most important impact of the research with low energy RIB is in nuclear astrophysics. The possibility of measuring the cross sections of capture reactions of astrophysical interest involving exotic nuclei will certainly have important consequences in the models of the primordial as well as in the explosive nucleosynthesis. The primordial nucleosynthesis involves reactions with light nuclei that would be accessible with RIBRAS beams. In the inhomogeneous model of the primordial nucleosynthesis there are new paths near the neutron drip line involving nuclei like \( ^8\) Li, \( ^6\) He that would lead to the synthesis of \( ^{11}\) B [6].

The RIBRAS facility will have several important up-grades provided by the linear post-accelerator (LINAC). In particular, radioactive ion beams with higher energy (up to 10 MeV/nucleon) and higher mass (perhaps up to \( A = 50 \)) can be produced with beam purities approaching 80% in many cases. In addition, the pulsed time structure of the beam will provide a time-of-flight parameter that can be used to reduce backgrounds in many experiments. On a more speculative note, if uranium beams could be accelerated to energies of a few MeV per nucleon, transfer induced fission reactions could be used to produce a wide variety of very neutron rich fission fragments. The beams formed in this way are not likely to be very pure, but they could be useful in a number of experiments. However, this extended project would require the installation of a low-\( \beta \) initial acceleration stage and an ECR source at the LINAC.

In Table I we present some typical production rates and reactions used at Notre Dame and at RIBRAS, São Paulo.

![Table 1.](image)

<table>
<thead>
<tr>
<th>Production reaction</th>
<th>secondary beam (part/s/( \times ) Amp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ^8) Be((\text{Li, Li})^{(*)} )</td>
<td>( 10^6 )</td>
</tr>
<tr>
<td>( ^8) Be((\text{Li, He})^{(*)} )</td>
<td>( 10^6 )</td>
</tr>
<tr>
<td>( ^4) He((\text{Li, Be})^{(*)} )</td>
<td>( 10^6 )</td>
</tr>
<tr>
<td>( ^4) He((\text{Li, n})\text{B} )</td>
<td>( 10^6 )</td>
</tr>
<tr>
<td>( ^{12}) C((\text{O, F})^{(*)} )</td>
<td>( 10^6 )</td>
</tr>
</tbody>
</table>

\( (*) \)Production reactions measured at RIBRAS using only 1 solenoid.
facilities and methods

The secondary beam spot measured at the PPAC position was about 7 mm in diameter which is consistent with a primary beam spot size of 4–5 mm multiplied by a magnifying factor of 1.5 of the first solenoid. Figure 3 shows the $\Delta E$-$E$ telescope spectra with the solenoid tuned to select $^8\text{Li}$ and $^6\text{He}$ ions respectively. The production rates measured at RIBRAS for these two exotic ions were of $10^4$ p/s and $10^5$ p/s respectively with a 300 nAe of primary beam. One can observe the presence of contaminants in the secondary beam like $^7\text{Li}^{2+}$ degraded primary beam and light particles. These contaminants can be eliminated by the second solenoid using a degrader in the crossover point. The operation of the second solenoid depends on the installation of the secondary scattering chamber that is under construction.

In conclusion, a double superconducting 6.5T (5T.m) solenoid system is installed at the Pelletron Laboratory of the University of São Paulo to produce secondary beams of radioactive nuclei. The two solenoids were mounted and tested on the 45B beam line of the Pelletron experimental area. The system began its operation using only the first solenoid and the $^7\text{Li}$ primary beam of the 8MV Pelletron Tandem. Secondary beams of $^6\text{Li}$, $^7\text{Be}$ and $^4\text{He}$ were produced. Experiments using these secondary beams are in progress.

References

Figure 2. X-Y Position spectrum (PPAC) of the $^8\text{Li}$ secondary beam.

Figure 3. Left panel: E-$\Delta E$ spectrum of the $^8\text{Li}$ secondary beam produced by the $^9\text{Be}(^7\text{Li},^8\text{Li})^9\text{Be}$ reaction. Right panel: E-$\Delta E$ spectrum of the $^6\text{He}$ secondary beam produced by the $^9\text{Be}(^7\text{Li},^6\text{He})^{10}\text{B}$ reaction.
facilities and methods

BEN@ECT*: The New 1Tflop/s Computing Facility at The European Centre for Theoretical Studies in Nuclear Physics and Related Areas

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Q2 AU: City?
BEN@ECT*: The New 1Tflop/s Computing Facility at The European Centre for Theoretical Studies in Nuclear Physics and Related Areas

**Introduction**

One current trend in most branches of contemporary research is the adoption of large computing facilities, capable of calculating models of ever increasing complexity. This is particularly true for Nuclear Physics, a discipline that has often prompted the development of new theoretical and numerical methods that stimulated the advance of computing machinery.

The need for better computational hardware was recognized by the ECT* Board in 2003, with the decision to start a joint program between the Istituto Nazionale di Fisica Nucleare (INFN) [1], the Istituto Trentino di Cultura (ITC) [2], the Provincia Autonoma di Trento (PAT) [3], and Exadron [4], the High Performance Computing Division of the Eurotech [5] group.

The result of the cooperation is an advanced computing infrastructure, centered on a 1TFlop/s cluster and an innovative networking technology, especially suited for the exacting needs of a distributed community of researchers.

One important aspect of the ECT* installation is the development of a pioneering network technology that aims at improving the current state of the art in clustered computing. In fact, although numerous commercial products are already available (Infiniband, Myrinet, Quadrics, etc.), their general purpose design does not necessarily fit optimally with the technical requirements for scientific computing.

One important aspect of the ECT* installation is the development of a pioneering network technology that aims at improving the current state of the art in clustered computing. In fact, although numerous commercial products are already available (Infiniband, Myrinet, Quadrics, etc.), their general purpose design does not necessarily fit optimally with the technical requirements for scientific computing.

The deployment of the 1TFlop/s computing facility is at an advanced stage: the cluster is already in production, with standard networking; the boards and software layer for the new inter-node connectivity technology are under production and will be installed shortly.

Finally, it should be remarked that the ultimate goal of the project is to bring the capabilities of the new facility to a large number of users: soon after the public opening of the system, a Call for Proposals will be addressed to a broad spectrum of scientists. This initial phase is expected to evolve naturally toward the participation to a “GRID,” or “GRID-like” environment that could allow the sharing of computational power among an enlarged community of researchers both from Academia and Industry.

**Priorities**

The computing facility stems from the need to fulfill a set of requirements that are of significant interest for the scientific community:

1. To develop a novel network technology, capable of overcoming the limitation of the traditional approaches;
2. To provide a computing resource adequate for the most advanced projects;
3. To allow and promote the sharing of knowledge between a distributed base of users, with particular attention for young researchers;
4. and, therefore, to qualify for becoming a “GRID” node.

The primary goal of this installation is to foster projects that are aligned with ECT* scientific activities; however, it is open to projects and initiatives belonging to different domains.

The other ambitious goal that was set is the attempt to demonstrate that it is possible to overcome the many obstacles that often separate Theoretical Science and Engineering. In fact, most of the traditional networking technologies used in high-performance computers were not designed having in mind the special needs of scientific computing. For this reason, ECT* decided to become the test-bed for a novel device that has been developed by the APE group of INFN and Exadron.

This new hardware derives from a 10-year-long experience in the APE project [6,7], one of the most successful European initiatives for the creation of a series of massively parallel...
facilities and methods

Figure 1. One example of the three cabinets composing the ECT* cluster. The computational units are encased in a very compact blade format (up to 20 CPUs in 3U).

supercomputers dedicated to lattice computing. In particular, one peculiar aspect of the APE supercomputer is how the inter-node communication is implemented [8]. Now, a technology based on the experience drawn from the APE project is going to be installed in the ECT* machine. This will allow for a better control over the interaction of the different components.

Due to its experimental nature, it is possible that the overall configuration of the system might change over time, in order to adapt to the evolution of the networking technology.

From the user’s point of view, the system provides a rich set of facilities that include:

- GNU [12] and other Open Source compilers for the most common languages (FORTRAN, C, C++, JAVA, etc.).
- Scientific and general libraries (MPI [13,14], ATLAS [15], BLAS [16], CERNLIB [17], FFTW [18], etc.).
- Job scheduling and administration tools (Torque [19], Maui [20]).
- Hardware status monitoring (Ganglia [21]).
- A number of applications on request by the users.

3-D Network Technology

The novel 3-D inter-node connectivity technology developed by the initiative consists in a PCI-X board compatible with any standard server that provides 6 full-duplex channels. Each channel has a nominal speed of 6.4 Gb/s for each direction with an overall estimated latency of 6.3 μs (preliminary drivers). This figure includes the PCI bus latency; this means that the actual fabric latency is negligible. The device is characterized by three major functional blocks:

- The PCI-X interface.
- The embedded crossbar switch.
- The communication links.

Each board is connected to the 6 neighboring nodes via differential links, therefore implementing a 3-D mesh of links. According to this scheme, it is possible to establish a direct transmission with those nodes that are actually interested in most of the communications occurring in a lattice/mesh calculation. The packets directed to other nodes are routed, thanks to the embedded crossbar switch that relays them, to the next board. The cost of traversing a large mesh side-to-side is negligible and amounts to few clock cycles per node traversed (nanoseconds). Therefore, it

Table 1. Overall features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing nodes</td>
<td>96</td>
</tr>
<tr>
<td>File server nodes</td>
<td>3</td>
</tr>
<tr>
<td>Master node</td>
<td>1</td>
</tr>
<tr>
<td>Total peak performance (RPeak)</td>
<td>1.1 TFlop/s</td>
</tr>
<tr>
<td>Expected performance (RMax) (Gbit eth)</td>
<td>0.6 TFlop/s</td>
</tr>
<tr>
<td>Expected performance (RMax) (APE tech)</td>
<td>~0.8 TFlop/s</td>
</tr>
<tr>
<td>Total RAM capacity</td>
<td>100 GByte</td>
</tr>
<tr>
<td>Total Disk capacity</td>
<td>4 TB (internal) + 4.8 TB (external arrays)</td>
</tr>
<tr>
<td>Inter-node network (Gigabit Eth)</td>
<td>2 independent networks (MPI and filesystem)</td>
</tr>
<tr>
<td>Inter-node network (APE tech)</td>
<td>6-neighbor flexible topology</td>
</tr>
</tbody>
</table>
is possible to effectively build a switchless infrastructure (i.e., without a central switch or a tree of switches) that is highly optimized toward patterns of traffic that exhibit heavy local communications, without having to pay a penalty for non-local transmission.

Specific drivers have been developed for the Linux kernel: both 2.4 and 2.6 kernel series are supported. The MPI libraries are being recoded in order to allow a smooth execution of standard parallel codes on the system. While not yet complete, a subset of the functions provided by MPI is available: for instance, it is possible to compile and run codes such as the HPL benchmark.

### Projects and Opportunities

Whereas a number of internal projects are emerging, external proposals are most welcome and will be evaluated by an ad hoc commission as soon as the cluster has been opened to the public.

For this reason, ECT* will stimulate the participation to its high-performance computing initiative with a Call for Proposals addressed to a broad spectrum of scientists. Although the main focus of the Centre is Nuclear Physics and related areas, any innovative and computationally demanding project will be accepted for evaluation: in particular, both theoretical and applied proposals for GRID-related and/or interdisciplinary work will be welcome.

### Industrial Partnership

It is worth mentioning the active role that Exadron, one of the few supercomputer manufacturers in Europe, is having in this project. In fact, Exadron has devoted a significant amount of internal resources to the development of the cluster facility.

Whereas most cluster installations use commodity hardware that has not been designed for scientific applications, Exadron has developed a number of crucial components specifically for the needs of the research community.

Moreover, Exadron is the industrial partner of the APE group, another key player of the project.

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**Table 2. Computing node features.**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPUs</td>
<td>2 × Xeon @ 2.80 GHz</td>
</tr>
<tr>
<td>RAM</td>
<td>1 GB</td>
</tr>
<tr>
<td>Local Disk capacity</td>
<td>40 GB</td>
</tr>
<tr>
<td>Network interfaces</td>
<td>2 × Gigabit eth + 1 × APE tech</td>
</tr>
</tbody>
</table>

---

**Figure 2.** Clockwise: the functional blocks of the inter-node communication board; one production board; a “naked” prototype board.
facilities and methods

The fruitful cooperation established with the ECT* High Performance initiative is going to have a pivotal role in the development of an entire family of high performance products, therefore demonstrating that Technology Transfer is a real opportunity even for a centre mainly focused on theoretical studies, as ECT* is.

The ECT* computing facility has been named Ben in honor of Prof. Ben Mottelson, the first director of the Centre.

Figure 3. 3-D hardware mesh (only part shown for clarity). Each circle represents a computational unit. Each "tower" is a cabinet with 32 computational nodes. Extremities are connected together with wrap-around links (not shown).

References
1. Istituto Nazionale di Fisica Nucleare (INFN) – http://www.infn.it/
2. Istituto Trentino di Cultura (ITC) – http://www.itc.it/
4. Exadron, the HPC Division of the Eurotech Group – http://www.exadron.com
5. http://www.eurotech.it
11. GNU Free Software Foundation—http://www.gnu.org
17. http://www.fftw.org/
Recent Achievements in Multinucleon Transfer Reaction Studies at LNL

Q1 AU: publisher or editor missing
Q2 ED: use photo placement
Recent Achievements in Multinucleon Transfer Reaction Studies at LNL

Introduction

What makes the field of nuclear reactions with heavy-ions so rich is the fact that the nucleus presents both the degrees of freedom associated with the single particle motion and those associated with the strong surface vibrations and rotations. In the low energy regime (close to the Coulomb barrier) it is the interplay of these two kinds of degrees of freedom that governs the evolution of the reaction from the quasi-elastic to the more complex deep-inelastic and fusion regimes. The quasi-elastic reactions, where few quanta are exchanged between target and projectile, constitute the most important tools for nuclear structure and reaction dynamics studies [1]. From the stripping and pick-up of neutrons and protons one can deduce informations about the shell structure close to the Fermi surface (one-particle transfer) of the two reactants or one can study nuclear correlations in the nuclear medium (multi-nucleon transfer reactions) [2–4]. Among these correlations of particular importance are the pairing one, that is, the ability of two nucleons to form a pair with zero angular momentum [1,2].

Extensive work using different heavy ion reactions has been performed during last few years with the time-of-flight magnetic spectrometer PISOLO, installed at the Laboratori Nazionali di Legnaro (LNL) [5]. The variety of channels that could be observed in several experiments allowed to follow in a systematic way the population pattern of the reaction products in the Z-A plane [6,7]. Parallel to this experimental work, semi-classical models have been implemented [8,9] that are able to treat quasi-elastic and deep-inelastic processes in terms of few and well-known degrees of freedom and that allow a quantitative comparison with the experimental observables.

Multinucleon transfer reactions constitute also a valuable tool to populate neutron-rich isotopes, at least in specific mass regions [10]. The study of the lowest excited levels of neutron-rich nuclei is an area of increasing interest for the verification of the predicted changes of the shell structure and of the nucleon-nucleon correlations far from the β-stability valley. A very powerful technique for these studies is constituted by the coupling of large gamma arrays detectors with the new generation of large solid angle spectrometers. At LNL the PRISMA heavy-ion magnetic spectrometer [11] coupled to CLARA [12] recently entered into operation.

Results from Inclusive Measurements with PISOLO

From the comparison between one and two particle transfer processes one can already learn a lot on the interplay between single-nucleon and pair-transfer modes, but it is only when several number of nucleons are transferred that one has a better view on how the mechanism evolves. An example of a complete measurement performed with PISOLO is that for the $^{58}$Ni+$^{208}$Pb system [7]. The experimental total angle and Q-value integrated cross-sections for pure neutron pick-up and pure proton stripping channels are reported in Figure 1 in comparison with the calculations performed within the semiclassical Complex WKB (CWKB) model (see Ref. [7] and references therein for details).

The experimental data show, for neutrons, a quite regular drop of the cross-sections as a function of the number of transferred nucleons, indicating that the transfer mechanism is likely to proceed as a sequence of independent single-particle modes. Similar results have been obtained at Argonne [13]. With the dotted line in Figure 1 we show the calculations made treating the transfer in a successive approximation and considering all the transitions as independent. A good agreement with the data is obtained for all pure neutrons transfer channels and for the stripping of one proton. However the calculation misses the massive proton transfer channels underpredicting the two-proton stripping by an order of magnitude. The discrepancies indicate that the theory should incorporate more complex transfer degrees of freedom. By adding to the reaction mechanism the transfer of correlated pairs of protons and neutrons, in the macroscopic approximation, and fixing the strength of the formfactors to reproduce the pure $-2p$ channel, one sees (dashed line) that the predictions for all other charge transfer channels are much better whereas no appreciable modifications are visible for the neutron transfer channels (dotted and dashed lines almost overlap with the full line in the right panel and are not shown). Because the pairing interaction has the same strength for neutrons and protons we kept the same form factors for...
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the +2n and −2p channels. The contribution of the pair mode for neutron is negligible due to the fact that its effect is masked by the successive mechanism; notice, in fact, that the cross-section for the +1n channel is almost a factor ten larger than the one of −1p channel. In multi-nucleon transfer channels large energy losses are reached, therefore the final yield can be considerably altered by evaporation, mostly neutrons. Including these evaporation effects a much better prediction is obtained for the final cross-sections, as shown by the full line in Figure 1. The calculation includes the transitions among all the single particle levels of target and projectile of a full shell below the Fermi surface and of all the ones above. To see if this choice of the shell model space is adequate for these reactions we look at the Total Kinetic Energy Loss (TKEL) spectra. In Figure 2 are shown TKEL distributions for the system 62Ni+206Pb, measured [6] at three bombarding energies, for an angle close to the grazing one.

Figure 2 shows that only the +1n and +2n channels have the main population concentrated in a narrow low energy region (close to the ground-ground state transition), and the theory gives a very good description, whereas for more massive transfer channels the populations widen and shift toward more negative Q-values developing tails that increase with the number of transferred neutrons. This may indicate that, even for this system where all neutron transfer pick-up channels are at optimum Q-value, the “cold” transfers (associated with low excitation energy) are hindered by processes that drive the population toward high excitation energy. By looking at the angular distributions of the same channels one sees that they display a bell-shaped form (underlying the grazing character of the reaction) with a width that increases with the number of transferred particles in particular in the forward direction.

These observations, both in the TKEL and angular distributions, indicate the relevance of the surface degrees of freedom. It is, in fact, the surface dynamics, governed by the low lying modes, that allows the two ions to stay in close contact for longer times and thus to build up a “neck” between the two colliding partners.

Quite interesting expectations are coming by looking at the Q-value distributions of the 40Ca+208Pb reaction [14]. Figure 3 shows the TKEL distributions at three bombarding energies for the two-neutron pick-up channel in comparison with CWKB calculations. As can be appreciated, the two neutron pick-up channel displays at all measured energies a well defined maximum, which, within the energy resolution of the experiment, is consistent with a dominant population, not of the ground state of 42Ca, but of states with an excitation energy at around 6 MeV. From the theoretical calculations one can see how the different single particle levels are populated in the reaction. The inspection of this population for the +2n channel tells us that the maximum of the distributions correspond to the transfer of two neutrons in the p_{3/2} orbital; note that the single particle form-factors for the p_{3/2} orbital are much larger than the one for the f_{7/2} orbital that constitutes the main configuration of the ground state of 42Ca. The (p_{3/2})^2 configuration corresponds to the main component of the excited 0+ states at around 5.4 MeV of excitation energy that were interpreted as multi (additional and removal) pair-phonon states [2]. These results open, at least in our expectation, the possibility to study multipair-phonon excitations. The strong concentration of strength near 6 MeV.
of peculiar $0^+$ states for $^{42}\text{Ca}$ (they must contain the $(p_{3/2})^2$ configuration) is clearly visible in the bottom part of Figure 3, where the strength distribution $S(E)$ coming from large scale shell model calculations is shown [14].

Measurements with the PRISMA Large Solid Angle Spectrometer

From the discussion in the last section it is clear that for the definite assignment of the states at around 6 MeV in $^{42}\text{Ca}$ it would be important to distinguish the population to specific nuclear states and to determine both their strength distribution and decay pattern. This, in fact, carries information on the wavefunctions of the populated levels and on the pairing correlation [1]. Experiments in this direction must exploit the full capability of spectrometers with solid angles much larger than the conventional ones, and with $A$, $Z$, and energy resolutions sufficient to deal also with heavy mass ions. This is now possible with the PRISMA spectrometer [11] designed for the $A=100–200$, $E=5–10$ MeV/amu heavy-ion beams of the accelerator complex of LNL. First experiments on heavy-ions grazing collisions have been already performed with beams in the $A=40–90$ range. One of the present interests are nuclear structure studies of neutron-rich nuclei, populated at relatively high angular momentum, by means of binary reactions. These studies are performed by combining PRISMA with the CLARA gamma-array [12], recently installed close to the target point and consisting of an array of 24 Clover detectors from the Euroball collaboration. With stable beams and at the energies and intensities typical of tandem accelerators, one can presently reach regions moderately far from $\beta$-stability (on average 3–5 nucleons from the last stable isotope), but one can investigate nuclei through the entire nuclear chart, provided suitable projectile/targets are chosen.

An exploratory run with PRISMA+CLARA has been very recently done by using the reaction $^{90}\text{Zr}+^{208}\text{Pb}$ with the main aim of looking at the yield production of specific $Q$-value ranges in the Zr and Sr.
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One observes different relative yields in mass spectra for each isotope, due to the different gamma multiplicities for the various multinucleon transfer channels populated in the reaction. In the bottom part is shown, as an example, the coincident gamma spectrum for $^{90}\text{Zr}$, obtained after Doppler correction for the projectile-like nuclei selected by the spectrometer. In general, the Zr isotopes span a range from spherical to highly deformed shapes and it would be therefore interesting to investigate in detail the change of the population strength and decay pattern properties of specific levels populated via multinucleon transfer mechanism.

Acknowledgments

In this report we have presented the results of the collaboration with the following people: S. Beghini, E. Fioretto, A. Gadea, G. Montagnoli, F. Scarlassara, A. M. Stefanini, S. Szilner, M. Trotta. The third section involves the whole PRISMA-CLARA collaboration.

References


Figure 3. Experimental (histograms) and theoretical (curves) total kinetic energy loss distributions of the two neutron pick-up channels at the indicated energies. The arrows correspond to the energies of $0^+$ states in $^{42}\text{Ca}$ with an excitation energy lower than 7 MeV. Bottom panel shows the strength function $S(E)$ from shell model calculations (see Ref. [14] for details).

Figure 4. Panels (a) and (b): mass distributions for Zr isotopes obtained in the $^{90}\text{Zr} + ^{208}\text{Pb}$ reaction at $E_{\text{lab}}=560\text{MeV}$ and at $\theta_{\text{lab}}=54^\circ$, without (a) and with (b) gamma coincidences. Panel (c): single gamma spectrum of $^{90}\text{Zr}$. The peak at 2186 keV corresponds to the lowest $2^+ - 0^+$ transition.
facilities and methods


L. Corradi (left) and G. Pollarolo (right).

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Atomic Nuclei at the Extreme Values of Temperature, Spin, and Isospin, XXXIX Zakopane School of Physics, 31 August–5 September 2004, Zakopane, Poland

In 2004 the XXXIX Zakopane School of Physics (31 August–5 September, http://chall.ifj.edu.pl/~maj/Zakopane2004/) was organized by Adam Maj from the Instytut Fizyki Jądrowej PAN in Krakow as a five day International Symposium. The program was concentrated on the nuclear structure problems in nuclei at extreme values of temperature, spin, and isospin. The meeting was also intended to celebrate, on the occasion of his 60th birthday, the remarkable achievements of Rafal Broda, a pioneer in study of neutron rich nuclei with gamma spectroscopy from deep inelastic collisions.

The meeting gathered 120 participants from 15 countries to discuss in a very relaxed and excellent atmosphere the state of the art of the nuclear structure research and the projects underway for future activities. Whereas the overviews of the different topics in the field were given by the invited lectures and seminars, the selected shorter contributions complemented very well the discussion started by the longer talks. It is important to stress that several presentations were given by bright young researchers and graduate students demonstrating very high capabilities from which the community will surely benefit for present and future projects. In addition, physicists could discuss together more informally in the afternoons either by strolling around or by taking part in the organized hiking excursions on the very panoramic trails in the mountains. Both for high scientific quality and for the organization in general the Zakopane School has been always very well recognized by the international community. This is testifed to by the fact that several participants in this meeting have also attended many of the others of this series in the past.

The symposium was opened the first evening by A. Budzanowski (director of IFJ PAN Krakow) with a lecture on phase transitions in highly excited nuclei reviewing the different experimental signatures pointing to the observation of the liquid-gas phase transition of expanding nuclear matter.

In the following four days the symposium was chaired by four conveners, Bent Herskind for the nuclei at highest spin, myself for nuclei at high temperatures, Hans-Juergen Wollerthesim for exotic nuclei investigated with radioactive beams, and Bogdan Fornal for neutron-rich nuclei studied with stable beams.

The program of the session on nuclei at the highest spins was mainly concentrated on the impressive results obtained with the large arrays Euroball and Gammasphere. It is important to stress that these arrays were designed and constructed after the first and very successful activity in the field of high spins led by Frank Stephens, Bent Herskind, and Peter Twin—the last two awarded this year with the Lise Meitner prize for nuclear science. The highlight on the key question of extreme deformations are the new findings of very large deformations in the light and medium mass nuclei (presented by W. Meczynski and P. Fallon), of the superdeformed triaxiality and wobbling motion (presented by G. Hagemann). In addition interesting results were obtained for high-K structures at extreme conditions (presented by P. Walker), research of interest also with radioactive beams. The progress made in the understanding of the structure of shell-stabilized highly rotating heavy nuclei has been discussed by T.L. Khoo while that chirality in rotation was presented by J. Srebrny. Particularly interesting has been the discussion on the search of hyperdeformed configurations that was triggered by the theoretical talk of J. Dudek and by the experimental talks of H. Huebel and Nyako illustrating the different results from several experiments. The problem of hyperdeformation is still open and we can say that we are in a situation similar to that we had at the beginning of the 1980s for the problem of superdeformation, namely some signals from the quasi continuum are present whereas the indications from discrete lines are very weak. Therefore it is clear to the community that it is important to pursue this research in the future with more efficient and selective arrays like AGATA and GRETA. The status of these new arrays, designed and supported first by the European and second by the American scientists, has been presented by J. Simpson.

The session on nuclei at high temperature focused on the study of high-lying collective modes built on both the ground state and on hot rotating
nuclei. The overview of the work on the electric dipole strength below the giant dipole resonance, based on the extensive work made at the University of Darmstadt, was given by J. Enders who pointed the interest in this topic in connection with neutron rich nuclei formed at the radioactive beam facilities. The status on the problem of the nuclear compressibility as obtained by the isoscalar monopole and dipole giant resonances has been presented by Y. Lui whereas new results on spin-isospin giant resonances were illustrated by A. Krasznohorkay. The future perspectives are related to the activity with radioactive beams and in particular at GSI a construction of a dedicated set up with a gas jet target is in progress (R3B and EXEL projects).

The new achievements in the field of nuclear structure at finite temperature have been discussed in connection with two different aspects. The first concerns the rotational damping and selection rules in the order to chaos transitions (S. Leoni) whereas the second concerns the gamma-decay of the giant dipole resonance in excited nuclei (F. Camera, M. Kicinska-Habior, F. Gramenegna, and M. Kmiecik). Recent data on the giant dipole resonance in excited nuclei have provided a better understanding of the damping mechanisms at finite temperature and of the isospin mixing.

In particular, the role of nuclear deformation in the dipole response at very high spins close to the fission limit has been investigated with Euroball experiments. New indications of the occurrence of the Jacobi shape transition (oblate–prolate) were found, transition that is also typical of gravitational objects rotating synchronously.

The session on exotic nuclei studied with radioactive beams was opened by T. Otsuka illustrating the new shell model predictions on the evolution of shell and collective structures in exotic nuclei. His results well describe the latest experiments at the RIB facilities and represent a useful guide for the future experimental programs. The status of the RISING facility at GSI has been presented giving both technical details (P. Bednarczyk) and the preliminary results of the first experiments (P. Reiter). These experiments concern the measurements of the B(E2) with Coulomb excitation and the study of isospin mixing in mirror nuclei using second fragmentation reactions. Similar and complementary activity on nuclear structure with fast exotic beams at lower energies is carried out at MSU and the main results were presented by A. Gade. The latest achievements concern nuclei in the vicinity of the N=Z=28 nucleus 56Ni a benchmark for the study of nuclear shells. A wealth of information on heavy neutron rich nuclei characterized by the presence of several isomeric states has been obtained with decay studies with stopped relativistic radioactive beams (Z. Podolyak). This research will be followed using the RISING set up focusing also on the interesting problem of the shape coexistence. On the same topic of the shape coexistence was the presentation of A. Goergen who reported on new investigations at GANIL on Krypton isotopes. The activity carried out at Oak Ridge with radioactive beams of ISOL type with few MeV/u has been presented by R. Grzywacz and K. Rykaczewski. They focused on Coulomb excitation measurements of “pure” beams of fission fragments such as the semimagic 82Ge and doubly magic 132Sn, sub barrier fusion and proton decay. Progress in the calculation techniques (K. Pomorski) on shell model in this mass region is also being made.

The session on the neutron rich nuclei investigated with stable beams was dedicated to Rafal Broda. This session was particularly lively and the lecturers (P. Daly, S. Lunardi, P. Regan, R. Janssens) made an excellent job in recalling how the technique based on deep inelastic collision was introduced by Rafal and how it then evolved with time. P. Daly pointed out that “scavenging pays” because in this way Broda and Fornal obtained very successful results. Nuclear structure programs using deep inelastic reactions have been carried out in different laboratories with the Gasp, Euroball, and GammaSphere arrays and many results obtained in different mass regions as those on 68Ni and 50Ca (presented by R. Broda) are at the basis of the current work with radioactive beams. The present and near future experiments are searching for more exotic nuclei and for short lived states at higher spin and they are carried out at the PRISMA-CLARA set up at LNL and at Argonne with GammaSphere equipped with the Chico particle detector.

The overview of the study of octupole deformations, of the rotating heavy nuclei as, for example, Nobeium and in general all the challenges for studying needles in a haystack were presented by P. Butler. He also pointed out the importance for second-generation radioactive beams of ISOL type as SPES at LNL, ISOLDE at CERN, SPIRAL2 at GANIL, and the European EURISOL project. These projects are all related to high-intensity beams. Beam of higher intensities are necessary also in the case of stable beams as it was discussed by F. Azaiez in order to make a substantial progress in the search of hyperdeformation, in the
study of spinning very heavy nuclei and of nuclei around $^{100}$Sn.

The symposium also included another event, namely the Ceremony of awarding the Diploma of the 2003 Zdzislaw Szymanski Prize to Marek Pfützner who gave a very good lecture on the current status of two-proton emission.

A March 2005 issue of *Acta Physica Polonica B* with the proceedings of the conference is in preparation. The next Zakopane School of Physics is planned for September 2006.

After such a successful symposium I have only two closing remarks: thanks to Adam Maj for his excellent work and happy birthday to Rafal Broda!

ANGELA BRACCO
*Universita’ di Milano and INFN*

**Symposium on “Atomic High-Precision Mass Spectrometry”**

Like only a few other parameters the mass is a characteristic nuclear property. Each nuclide comes with its own mass value different from all others (presently about 3,200 known or estimated) [1]. Thus the atomic masses are basic quantities of highest interest. High-accuracy mass measurements allow to determine nuclear and atomic binding energies and thus have a huge field of application that extends beyond nuclear physics [2]. In the case of short-lived exotic atomic nuclei it ranges from the verification of nuclear models to a contribution towards the test of the Standard Model, in particular with regard to the weak interaction and the unitarity of the Cabibbo-Kobayashi-Maskawa quark mixing matrix. As for mass measurements on stable atoms, they now reach a relative mass uncertainty of about $10^{-11}$. This extreme accuracy allows, among others, to contribute to metrology, that is, the determination of fundamental constants and a new definition of the kilogram, and to tests of quantum electrodynamics and Einstein’s energy-mass relation [3].

Several of these topics have been highlighted recently at a symposium on “Atomic High-Precision Mass Spectrometry” (http://www.dpg-tagungen.de/prog/syam/index.html) in the framework of the annual meeting of the German Physical Society. Eight distinguished international speakers from leading groups gave reviews and updates of important aspects of the field. The two sessions, each of four talks, have been moderated by E. W. Otten and G. Werth from the University of Mainz. Several short talks of young researchers have been added. In the following, we summarize the invited talks, which gave an excellent overview of this very active field.

Georges Audi of the CSNSM at Orsay started the symposium with “The History of Mass Spectrometry and the Atomic-Mass Evaluation.” He drew the main lines from the early days of mass spectrometry when Aston and Thomson discovered isotopism, to the development of Mattauch-Herzog mass spectrometers in 1930s, and to the first installation of a high-precision Penning-trap mass spectrometer in 1986. After this historical account he developed general ideas about data evaluation in nuclear physics and described the most prominent features of the Atomic-Mass Evaluation (AME), the reasons for its complexity, and how problems are faced and solved. He explained why it was found essential to create the NUBASE evaluation and how he finally succeeded in having AME and NUBASE coordinated and published for the first time together in December 2003 [1].

Although the systematic survey of all available data is an essential part of the nuclear-mass business, this data is of experimental origin, and thus has to be measured. H.-Jürgen Kluge of GSI at Darmstadt and the University of Heidelberg explained how to perform “High-Precision Mass Measurements on Radioisotopes in Storage Rings and Ion Traps.” He noted that in the last decade new ideas have been introduced for high-precision mass measurements of short-lived radionuclides that use the principle of ion trapping and cooling [4]. The new methods were pioneered on the small scale of ion traps by the triple-trap mass spectrometer ISOLTRAP [5,6] at ISOLDE/CERN, and on the large scale of storage rings by the Schottky and isochronous mass spectrometry at the experimental storage ring ESR at GSI/Darmstadt [7,8]. In the mean time, a large fraction of all directly measured masses in the chart of nuclei have been determined by these devices, and across the world many other Penning-trap facilities at accelerators are operational, in the building-up stage, or planned. The talk motivated and introduced the large variety of atomic and nuclear physics experiments with stored particles in ion traps [4].

In the following presentation Georg Bollen from the National Superconducting Cyclotron Laboratory at Michigan State University/East Lansing,
took that ball and reported about “Precision Mass Spectrometry of Rare Isotopes in America.” He again emphasized that accurate masses of nuclides far away from the valley of beta-stability are most important for the understanding of the nuclear many-body system as input for the modelling of the synthesis of the elements in the universe, and for tests of fundamental symmetries. Because Penning-trap mass spectrometry offers unprecedented accuracy and a very high sensitivity, in America, too, several Penning-trap mass spectrometers have been or are presently being built. These projects make use of unique rare-isotope production facilities and thus contribute to the worldwide effort to enhance the knowledge of nuclear binding energies [9]. The talk gave an overview of ongoing activities and the perspectives of reaching even more exotic nuclides: The Canadian Penning Trap mass spectrometer at Argonne recently started its experimental program [10]. LEBIT at the Michigan State University [11] and TITAN at TRIUMF/Vancouver [12] are in commissioning phase or under construction, respectively.

Although direct mass measurements built the data basis, theoretical models are as important when it comes to predict unknown nuclear masses far away from the valley of stability that are not (yet) in experimental reach. Piet Van Isacker from GANIL at Caen discussed the “Theory and Predictability of Nuclear Masses.” He reviewed the status of modern nuclear mass formulas [2]. This includes the elementary Weizsäcker liquid-drop formula and its refinements, such as the finite-range droplet model, as well as more microscopically founded attempts based on Hartree-Fock theory and the shell model. Special attention was paid to the recent suggestion that there might be a limit to the accuracy with which nuclear masses can be calculated in a mean-field approach and that chaotic motion inside the atomic nucleus is responsible for this lack of predictability [13,14]. In view of the important implications of this claim, for example, for nuclear astrophysics, its meaning was clarified with an empirical study of more than 2,000 nuclear masses. By use of Garvey-Kelson relations correlations among neighboring masses have been established where the root-mean-square deviation is below 100keV. This can be considered as a upper limit for the current predictability of nuclear masses.

The afternoon session started off with “Recent Trends in the Determination of Nuclear Masses” by Juha Aystö of the University of Jyväskylä, Finland. He reminded all participants that the mass of a nucleus is a mirror to the binding energy [2]. It is the result of the strong interaction acting in the finite many-body system of protons and neutrons, and thus carries fundamental information on the microscopic structure of the nucleus. The measurement of binding energies with relative accuracies in the range from $10^{-6}$ to $10^{-8}$ is necessary to unravel the predicted new phenomena in nuclear structure of exotic nuclei with extreme proton to neutron number ratios [15,16]. Precision measurements of nuclear masses also play an important role in nuclear astrophysics and fundamental symmetries and interactions [17–19]. The talk presented recent trends and in particular some precision mass measurements of exotic nuclei with high neutron excess, which are of interest for studies of the nuclear structure and the shapes of nuclei, as well as measurements of neutron-deficient nuclei of interest with respect to nucleosynthesis in stellar processes [20]. These measurements have become possible only recently due to the employment of Penning traps coupled to fast injection of ions. Selected results were taken from the ISOLTRAP facility at CERN and the JYFLTRAP-IGISOL facility [21] at the University of Jyväskylä.

After this talk the subject changed from mass spectrometry on radionuclides to high-precision mass measurements on stable ions. Reinhold Schuch of the Stockholm University reported on mass measurements with the SMILETRAP Penning-trap mass spectrometer, “A Precision Mass Balance Using Highly Charged Ions.” It exploits the merits of highly charged ions retracted from an electron-beam ion source. These ions are retarded in a first cylindrical Penning trap before a fraction of them is sent to the hyperbolic precision Penning trap where their cyclotron frequency is measured with a resolving power of $10^9$ [22]. In order to reduce the influence of magnetic-field variations the cyclotron frequencies of ions of interest and that of the reference ions are measured within durations as short as two minutes. Several mass measurements with a relative uncertainty in the region of 0.3 to a few ppb have been performed by use of ions with charge states 1+ to 52+ [22]. The nuclides investigated include $^{28,30}$Si for a new definition of the kilogram and the $^{76}$Ge-$^{76}$Se pair [23] to extract the $Q$ value of double-beta decay for the search of neutrinoless double-beta decay.

Edmund Myers from Florida State University reported about “Precision Mass Spectrometry with One and Two Ions in a Penning Trap,” which had been pioneered by David Pritchard at MIT. In the 1990s Prichards group developed a Penning-trap setup and established an atomic mass table with application to fundamental constants in a class of its own, namely at an uncertainty level of $10^{-10}$ [24]. The success of this mass spectrometer is
based on several special features such as a dc-SQUID detector and the use of a “pulse and phase” technique, analogous to the Ramsey Separated-Oscillatory-Field method. In the last few years an further technique has been developed: The two ions to be compared are positioned in the same trap in a coupled magnetron orbit. Their cyclotron frequencies are thus measured simultaneously. This method suppresses the uncertainty due to, for example, magnetic-field fluctuations by two to three orders of magnitude and allowed mass comparison with uncertainties as low as $7 \times 10^{-12}$ [3]. It led to the discovery of rotational state-dependent polarization-induced cyclotron-frequency shifts and a new test of Einstein’s $E=mc^2$.

In 2003 the mass spectrometer was relocated to Florida State University at Tallahassee where additional mass measurements at the 10$^{-10}$ level using single-ion techniques have been completed. Further development of the sub-10$^{-11}$ two-ion technique is in progress, in particular for a high-precision atomic-mass comparison of tritium/helium-3, which will be relevant to neutrino-mass research.

Finally, the series of symposium talks was completed by Gerald Gabrielse of the University of Harvard who extended the range of applications to “Highly Accurate Measurements of Particle and Antiparticle Masses.” He presented a number of fundamental tests via mass and charge-to-mass ratio comparisons including one of the most stringent test of the most fundamental symmetry of physics, namely CPT [25,26]. The mass comparison has been performed for both positrons versus electrons, that is leptons, and for antiprotons versus protons, that is, hadronic matter. Furthermore, the audience was reminded that ion trapping and in particular the Penning trap is not restricted to precision measurements of atomic masses. One particularly exciting aspect is the combination of positron and antiproton trapping. This recent development led to the creation of neutral antimatter in the form of antihydrogen by the “recombination” of simultaneously trapped antiprotons and positrons [27–30].

More than 7,000 physicists attended this year’s annual meeting of the German Physical Society at Berlin. They brought more than 5,000 contributions in the form of talks and posters. The symposium on “Atomic High-Precision Mass Spectrometry” was certainly a highlight.

References

KLAUS BLAUM
Johannes Gutenberg-Universität Mainz Germany

LUTZ SCHWEIKHARD
Ernst-Moritz-Arndt-Universität Greifswald Germany

Report on the 15th Panhellenic Symposium on Nuclear Physics

This year the annual symposium of the Hellenic Nuclear Physics Society was held on May 27 and 28 at the Physics Department of the Aristotle University of Thessaloniki. In the Symposium the most recent work of Greek nuclear physicists, working within or out of Greece, was reported. There were also invited speakers from abroad, as it is a tradition of the Society to invite distinguished foreign colleagues. More than 75 participants from 5 countries attended the meeting. The large participation of young colleagues at the M.Sc. and Ph.D. levels should be particularly noticed.

There were 40 talks covering many areas from Nuclear Structure and Reactions to Nuclear Astrophysics and Heavy Ion Physics and related areas.

This year, the guest of honor was Professor Dr. Peter Ring from the Physics Department of the Technical University of Munich. The Hellenic Nuclear Physics Society honored Professor Ring for his pioneering work in the nuclear many body problem and named him a honorary member of the Society.

GEORGIOS A. LALAZISSIS
Chair of the Organizing Committee
IBA-Europhysics Prize 2005 for “Applied Nuclear Science and Nuclear Methods in Medicine”

The Executive Committee of the EPS has approved the recommendation of the Nuclear Physics Board according to the proposal of the IBA-EPS prize selection Committee to award the IBA-Europhysics Prize 2005 to Prof. Dr. Werner Heil, Johannes Gutenberg Universität Mainz, Germany and Dr. Pierre Jean Nacher, Laboratoire Kastler Brossel, ENS Paris, France. The Prize is attributed with the citation: “For the development of spin polarized $^3$He targets by optical pumping and their applications in nuclear science and medicine: nuclear physics, neutron low temperature physics and medicine.”

The two winners are pioneers in the art of polarizing $^3$He by the method of metastability exchange optical pumping (MEOP) and applying it to several fields (electron scattering on polarized $^3$He targets, polarization of neutron beams, contrast agent for NMR tomography). Powerful techniques of polarizing $^3$He have been developed in the past for fundamental experiments in nuclear and neutron physics. The basis for an important application in medicine was prepared, the use of polarized $^3$He as a contrasts agent to image the air-spaces of the lungs and to check lung functions.

The IBA-Europhysics prize is sponsored by the IBA (Ion Beam Applications) Executive Committee, Chemin du Cyclotron, 1348 Louvain la Neuve, Belgium. It will be delivered during the XIX Nuclear Physics Divisional Conference “New Trends in Nuclear Physics Applications and Technology” in Pavia, Italy from September 5–9, 2005.

PROF. CH. LECLERCQ-WILLAIN
President IBA-EPS Selection Committee
Université libre de Bruxelles,
B 1050 Bruxelles

Prof. Dr. Werner Heil

Dr. Pierre Jean Nacher

Vol. 15, No. 3, 2005, Nuclear Physics News 1
2005
March 11–12
MPI Heidelberg, Germany. “New Trends in Nuclear, Atomic and Molecular Physics.”
Web: http://www.mpi-hd.mpg.de/
heavy-ion/65/

March 13–20
Bormio, Italy. XLIII International Winter Meetings on Nuclear Physics.
Web: bormio@mi.infn.it

March 19–23
San Servolo, Italy. FUSION'06, International Conference on Reaction Mechanisms and Nuclear Structure at the Columbia Barrier.
Web: http://www.lnl.infn.it/~fusion06/

March 29–April 1
Kloster Banz, Bavaria, Germany. Neutron-Rich Radioactive Ion Beams—Physics with MAFF.
Web: http://www.ha.physik.uni-muenchen.de/maff/
workshop/

May 16–20
Debrecen, Hungary. Nuclear Physics in Astrophysics—II.
Web: http://atomki.hu/~npa2/

May 16–22
Bonn, Germany. International Conference on Low Energy Antiproton Physics (LEAP-05).
Web: http://www.fz-juelich.de/leap-05

May 23–26
Bonn, Germany. 6th International Conference on Nuclear Physics at Storage Rings STORI05.
Web: http://www.fz-juelich.de/ikp/stori05/

May 27–31
Aschaffenburg, Bavaria, Germany. SHIM 2005: Swift Heavy Ions in Matter.
Web: http://www.gsi.de/SHIM2005

June 14–18
Web: http://www.matfys.lth.se/Nilsson

June 20–25
Web: http://atomki.hu/~ens05/

June 28–July 1
Peterhof, St. Petersburg, Russia. LV International Meeting on Nuclear Spectroscopy and Nuclear Structure “Frontiers in the Physics of Nucleus.”
Web: http://nuclpc1.phys.spbu.ru/nuclconf

August 30–September 6
Web: http://zfpavs.fuw.edu.pl/
mazurian/mazurian.html

September 5–9
Pavia, Italy. EPS XIX Nuclear Physics Divisional Conference (NPDC19).
Web: http://www.pv.infn.it/~npdc19

September 10–14
Zaragoza, Spain. Ninth International Conference on Topics in Astroparticle and Underground Physics (TAUP).
Web: http://www.unizar.es/taup2005

September 12–16
Caen, France. 11th International Conference on Ion Sources ICIS05.
Web: http://www.ganil.fr/icos05

September 12–17
Web: http://www.inp.demokritos.gr/~finustar

October 3–7
Igazu, Argentina. The Sixth Latin American Symposium on Nuclear Physics and Applications.

October 16–22
Dresden, Germany. Workshop on Critical Stability.
Web: http://www.mpipks-dresden.mpg.de

October 17–21
Web: http://www.ihep.ac.cn/apsorc2005

December 15–20
Honolulu, Hawaii, USA. “SCIENCE WITH RARE ISOTOPE BEAM.” Part of PACIFICHEM 2005.
Web: http://www.phy.cuhk.edu.hk/gee/pachem05/pacifichem.html

2006
September 2–6
Web: hussein@fma.if.usp.br
Second Announcement

Call for Abstracts

Asia-Pacific Symposium on Radiochemistry 2005 (APSORC-05)

About the Conference

The third international conference in the series of Asia-Pacific Symposium on Radiochemistry (APSORC-05) will be held in Beijing, China, during 2005 October 17–21. The first APSORC was held in Kumamoto, Japan (1997), and the second in Fukuoka, Japan (2001). The conference provides an international forum for presentation and discussion of current and emerging sciences in all fields of radiochemistry and nuclear chemistry, and their applications to various fields. It aims to promote academic activities in nuclear, radiochemical and related sciences. Scientists, engineers and students from universities, institutes, laboratories and industries throughout the world are encouraged to participate and make contributions.

Venue and hotel

The Symposium will be held at the Grand View Garden Hotel in Beijing. It is a four-star hotel with a beautiful view. The hotel website (http://www.gvghotel.com) is in both English and Chinese languages. A discount price will be provided to pre-registered participants at the rate of US$ 60 per person per diem for single occupancy and US$ 40 per person per diem for double occupancy in a standard room. A list of cheaper hotels will be provided upon request.

Language

The conference language is English.

Organization

Under the supervision of the APSORC International Committee (APSORC-IC), the Symposium is co-organized by:
Chinese Nuclear & Radiochemistry Society (CNRS)
China Institute of Atomic Energy (CIAE)
Institute of High Energy Physics (IHEP)
Peking University (PKU)
Tsinghua University (THU)

APSORC-05 is sponsored by the:
Chinese Academy of Sciences (CAS)
National Natural Science Foundation of China (NNSFC)
Chinese Chemical Society (CCS)
Chinese Nuclear Society (CNS)
Calendar

Query sheet

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calendar

2005

September 10–14
Zaragoza, Spain Ninth International Conference on Topics in Astroparticle and Underground (TAUP)
http://www.unizar.es/taup2005

September 10–15
Sant Feliu de Guixols (Costa Brava), Spain EuroConference on Ultracold Gases and their Applications.
Web: http://www.esf.org/esf
genericpage.php?section =10&language =0&gene ricpage =2

September 12–16
Caen, France 11th International Conference on Ion Sources ICIS05
http://www.ganil.fr/icis05

September 12–17
Kos, Greece Frontiers in Nuclear Structure, Astrophysics, and Reactions Conference (FIN)
http://www.inp.demokritos.gr/~finustar

September 19–24
Milos Island, Greece 6th Research Conference on Electromagnetic Interactions with Nucleons an 2005
http://www.iasa.gr/EINN 2005/

September 21–25
Kazimierz Dolny, Poland XII Nuclear Physics Workshop Marie and Pierre Curie “Nuclear Structure and Reactions”
http://kft.umcs.lublin.pl/wfj/

September 25–October 2
Albena, Bulgaria Third Sandanski Coordination Meeting on Nuclear Science.
Web: http://beo-db.inrne.bas.bg/ albena 2005/

September 26–December 2
Seattle, Washington, USA
Nuclear Structure Near the Limits of Stability
http://www.int.washington.edu/ PROGRAMS/05–3.html

September 28–30
Santiago de Compostela, Spain
R3B-EXL Workshop
http://www.usc.es/genp/Meetings/ R3BEXL Sant 05/

October 3–7
Iguazu, Argentina The Sixth Latin American Symposium on Nuclear Physics and Applications

October 3–7
Zurich, Switzerland Tracking in High Multiplicity Environments (TIME ’05)
http://ckm.physik.unizh.ch/time05/

October 10–12
CERN, Geneva, Switzerland
Nuclear Physics & Astrophysics at CERN - NuPAC
http://cern.ch/nupac

October 12–14
Frascati, Italy Workshop on “Nucleon Form Factors”
http://www.lnf.infn.it/conference/ nucleon05/

October 16–22
Dresden, Germany Workshop on Critical Stability
http://www.mpiiks-dresden.mpg.de

October 17–21
Beijing, China Asia-Pacific Symposium on Radiochemistry 2005
APSORC-05
http://www.ihep.ac.cn/apsorc2005

October 19–21
Caen, France Workshop on Reactions with SPIRAL 2
http://www.ganil.fr/research/ developments/spiral2/

October 31–November 1
CERN, Geneva, Switzerland
ISOLDE PAC Meeting
http://isolde.web.cern.ch/ISOLDE/

November 3–10
Bordeaux, France 10th Geant4 Conference

November 18–19
Groningen, The Netherlands
NuPECC Meeting
http://www.nupecc.org/misc/ communications.html

November 23–25
Brussels, Belgium 3rd International Conference on Education and Training in Radiological Prot
http://www.etrap.net/

November 28–29
Caen, France EURISOL Town Meeting
http://www.ganil.fr/eurisol/

November 28–December 1
Catania, Italy IWM2005-International Workshop of Multifragmentation and related topic
http://www.dg-talengine.it/ iwm2005/index.htm

December 12–14
GSI Darmstadt, Germany
PANDA Collaboration Meeting
http://www.ep1.rub.de/~panda/ auto/home.htm
calendar

December 15–20
Honolulu, Hawaii, USA “SCIENCE WITH RARE ISOTOPE BEAMS”, Part of PACIFICHEM 2005
http://www.phy.cuhk.edu.hk/gee/pachem05/pacifichem.html

2006
January 29–February 3
Bormio, Italy XLIV International Winter Meeting on Nuclear Physics.
Web: bormio@mi.infn.it.

March 6–10
Dresden, Germany PANDA Collaboration and Physics Meeting
http://www.ep1.rub.de/~panda/auto/home.htm

March 17–18
Athens, Greece NuPECC Meeting
http://www.nupecc.org/misc/communications.html

March 19–23
San Servolo, Venezia, Italy FUSION06, International Conference on Reaction Mechanisms and Nuclear S Coulomb Barrier
http://www.Inl.infn.it/~fusion06/

June 12–14
GSI Darmstadt, Germany PANDA Collaboration Meeting
http://www.ep1.rub.de/~panda/auto/home.htm

June 20–23
St. Goar, Germany 2nd International Conference on Collective Motion in Nuclei under Extreme (COMEX 2).
Web: http://www.ikp.physik.tu-darmstadt.de/comex2/

June 25–30
CERN, Geneva, Switzerland International Symposium on Nuclear Astrophysics Nuclei in the Cosmos — NI.
Web: http://indico.cern.ch/conferenceDisplay.py?confId=059

July 3–7
Cortina d’Ampezzo, Italy 7th International Conference on Radioactive Nuclear Beams (RNB7).
Web: http://rnb7.pd.infn.it/

August 21–26
Santos, Sao Paulo, Brasil 18th International IUPAP Conference on Few-Body Problems in Physics (FB18)
Web: http://www.fb18.com.br/

September 2–5
Vienna, Austria PANDA Collaboration Meeting
http://www.ep1.rub.de/~panda/auto/home.htm

September 2–6
Rio de Janeiro, Brasil International Conference on Nucleus-Nucleus Collisions NN2006
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