CONTEMPORARY NUCLEAR PHYSICS: FROM THE CORE OF MATTER TO THE FUEL OF STARS

BY GARTH HUBER

As we approach the centennial of Rutherford's discovery of the atomic nucleus, nuclear physics continues to be a challenging and dynamic discipline. A century ago, nuclear physics began as the study of the structure and properties of atomic nuclei as assemblages of protons and neutrons. Research focused on nuclear reactions, the nature of radioactivity, and the synthesis of new isotopes and new elements heavier than uranium. Great benefit, especially to medicine, emerged from these efforts. Today, nuclear physics is much more than this – its reach extends from the quarks and gluons that form the substructure of the once-elementary protons and neutrons, to the most dramatic of cosmic events, supernovae. From a theoretical and experimental perspective, strong parallels even exist between the structure of complex nuclei and structures of interest in the emerging field of nanoscience. The impact of nuclear physics can be seen not only in basic science, but also in nuclear medicine, nuclear power, and numerous practical applications. With its scope enlarged by landmark astrophysical discoveries and by the successful formulation of a theory of sub-nuclear matter, the study of nuclear physics is more broadly compelling than ever before.

THE KEY RESEARCH QUESTIONS

The current frontiers of nuclear physics involve fundamental and rapidly evolving issues. One is understanding the structure and behavior of strongly interacting matter in terms of its basic constituents, quarks and gluons, over a wide range of conditions – from normal nuclear matter to the dense cores of neutron stars, and even to the big bang. A second frontier is the quantitative description of the properties of atomic nuclei in terms of models derived from the properties of the strong interaction. These properties play a vital role in the nuclear processes that fuel the stars and produce the chemical elements. At stake is a fundamental grasp of how the universe has evolved and how the elements of our world came to be – two of the deepest questions in all of science. Yet another active frontier addresses the fundamental symmetries of nature that manifest themselves in the nuclear processes in the cosmos, such as the behavior of neutrinos from the Sun and cosmic rays, and in low and intermediate-energy laboratory tests of these symmetries. Thus, contemporary nuclear physics research covers a broad range of questions relating to the origin, evolution, structure and phases of strongly interacting matter. Here, these key questions are presented and used to place the Canadian nuclear physics effort in the broader international context.

SUMMARY

This article presents an overview of contemporary nuclear physics research in Canada, and a sample of its contributions to society. Special emphasis is placed on the major research topics and applied contributions of the members of the Division of Nuclear Physics (DNP) at the Canadian Association of Physicists (CAP) 2007 Congress.

A. Can we understand the structure of the nuclear building-blocks, and the phases of nuclear matter, in terms of QCD?

The standard model of particle physics now lies at the center of much nuclear physics research. One of the basic components of the standard model, the existence of quarks and gluons, was first inferred from the spectrum of elementary particles and from electron-scattering experiments. Subsequently, quantum chromodynamics (QCD) was developed to describe their interactions. Just as the formulation of Maxwell's equations led to a quantitative understanding of electromagnetic phenomena in the late 19th century, so the development of QCD a century later has provided the theoretical foundation for the understanding of many strong interaction phenomena. However, while physicists have known for some time that protons and neutrons (the nuclear building-blocks) are composite particles made up of quarks and gluons, we have only partial answers from high-energy physics to questions such as how the quarks are distributed in the proton and their intrinsic dynamics. Furthermore, QCD is still unsolved in the “confinement regime”, where the quark-gluon coupling strength is too large to allow perturbative theoretical methods to be reliably used. One of the central problems of modern physics remains the connection of the observed properties of protons and neutrons to the underlying theo-

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retical framework provided by QCD. At the highest densities but at still rather low temperatures (such as in neutron stars), the quarks and gluons making up the building-blocks of nuclear matter may form a new state of matter, which is color-superconducting. Nuclear matter can also be heated by absorbing energy from a relativistic collision. In this case, ‘nuclear temperatures’ can reach values that represent a state of matter (the quark-gluon plasma) that existed during the first moments after the big bang.

Experiments designed to make detailed comparisons with QCD predictions are high-priority endeavours of research at facilities across the USA and Europe, with goals of obtaining:

- a tomographic view of the quarks and gluons and their motion within the nuclear building-blocks (protons and neutrons).
- a detailed understanding of the how QCD gives rise to the properties of protons and neutrons, and how these properties are modified by the surrounding nuclear environment.
- an understanding of the phases of QCD over a wide range of temperatures and pressures, such as exist in neutron stars or in the moments after the big bang.

The Canadian experimental program in this field is entirely off-shore, and Canadians have leadership roles in a number of high priority experiments designed to advance our understanding of QCD in the “confinement regime”.

A 2006 CAP Congress session titled “Hadron Form Factors” profiled a number of experiments at Jefferson Lab (USA) where the Canadian contributions are particularly large. These included the G^0 experiment, which aims to determine the strange quark currents in the proton, the recent results on the charge and current distributions inside the proton, and comparisons of pion electromagnetic form factor data to QCD model calculations.

At the 2007 Congress, Adam Sarty (Saint Mary's) presented preliminary low-energy deuteron photodisintegration data from Jefferson Lab. In deuteron photodisintegration below a few hundred MeV of excitation energy, the measured cross sections and polarization observables are all well described by hadronic theories based on the conventional nucleon-nucleon interaction. However, above roughly 300 MeV there is a clear discrepancy for the so-called induced proton polarization which remains 30 years after first being observed. This discrepancy has been attributed to the onset of explicit quark-gluon degrees of freedom in the description of the deuteron, and the new data are intended to settle this question by focusing in on whether this discrepancy with hadronic models is real, and (if so) whether it can be rectified within the standard hadronic framework.

The resolution of the questions listed above also requires substantial advances in theory. Recent advances in lattice QCD, in combination with chiral perturbation theory, make it possible to extrapolate full lattice QCD simulations to physical quark masses, and thus allow direct comparison to experimental observables. Lattice QCD thus holds the promise to revolutionize our understanding of QCD as applied to a wide range of phenomena, and from the beginning, Canadian theorists have been major contributors. Canadian theorists have also contributed significantly to the radiative corrections necessary for studies of the internal structure of the proton as well for precision tests of the standard model.

Aleksandrs Aleksejevs (Saint Mary's) presented at the 2007 Congress the impact of radiative effects on parity violating electron-proton scattering. Although the corrections associated with these effects have been under constant review over the past few years, there is still a substantial amount of uncertainty coming from the hadronic sector. He discussed the degree of influence hadronic radiative effects have in electron-proton scattering, and he compared his results to the G^0 experimental data, which are sensitive to the strange and axial form factors of the proton.

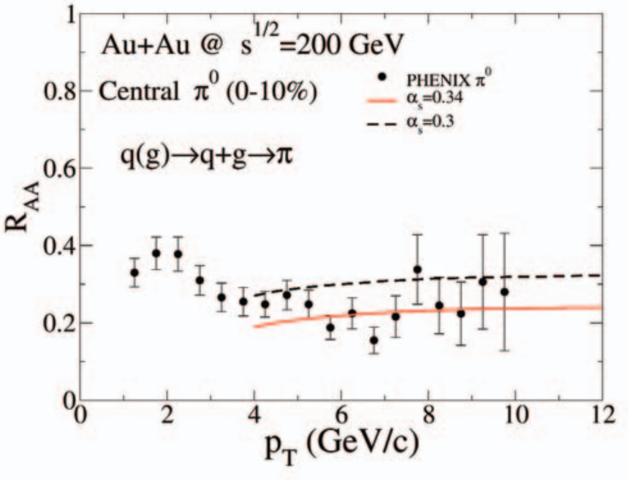

Fig. 1 When heavy ions collide at relativistic energies, the resulting system may be hot and dense enough to free quarks and gluons from the confines of hadrons, creating a quark-gluon plasma (QGP). A convincing way to show that such a system is created is to compare pion spectra from gold-gold and proton-proton collisions. The plotted quantity R_{AA} is the nuclear modification factor, normalized so that $R_{AA} = 1$ if every energetic parton escapes the fireball unscathed, but $R_{AA} = 0$ if every energetic parton is stopped by the surrounding medium. Here, the hot QGP calculations by Turbide, Gale, Jeon and Moore are compared to data from the PHENIX collaboration at RHIC. Their good agreement indicates that jets are indeed being quenched in this new form of matter.

Canadian theorists are also making significant contributions to our understanding of the phase diagram of nuclear matter. Their work has significant bearing for terrestrial searches for the quark-gluon plasma, and for our understanding of astrophysical phenomena such as neutron star structure and the evolution of the early universe. As an example of this work,

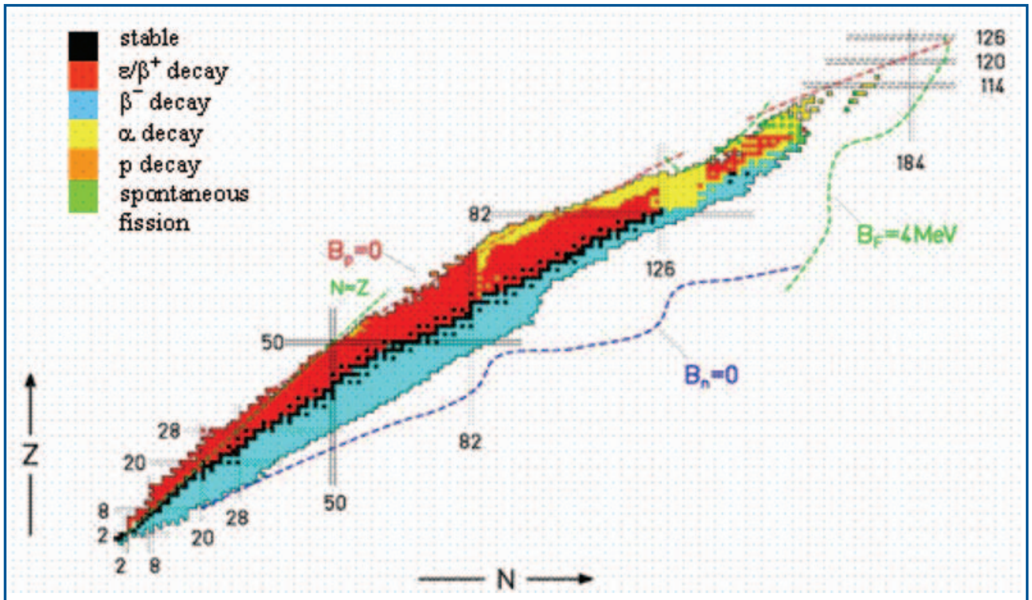

Fig. 2 Chart of the nuclides displaying the stable nuclei (black), and unstable nuclei with their prominent decay modes. The lines indicate where the respective binding energies of the last proton and neutron are zero (labelled by $B_p = 0$, $B_n = 0$), and where instantaneous fission occurs ($B_f = 4$ MeV). These three lines show the possible limits of existence. The limit is fairly well understood for proton-rich nuclei (those to the left of the stable nuclei), but the neutron-rich side is not known beyond oxygen ($Z = 8$).

Sangyong Jeon (McGill) presented a study on jet energy loss in a hot quark-gluon plasma (Fig. 1). When a quark or gluon (a parton) is emitted with high energy in a relativistic heavy ion collision, a 'jet' of hadrons is produced. As this jet propagates away from the interaction region, it must traverse the quark-gluon plasma created in the collision. As it does so, the jet interacted with the hot and dense medium, losing a portion of its energy. The changes in jet properties then reflect the properties of this new state of matter which naturally existed only within a few microseconds after the big bang. So far, several jet energy-loss scenarios have been proposed that can explain the current data from the Relativistic Heavy Ion Collider (RHIC). Jeon summarized the strong points as well as the weak points of this new approach which takes into account full leading order thermal QCD effects.

B. What is the structure of nuclear matter?

The original and central goal of nuclear physics remains to explain the properties of nuclei and nuclear matter. This is a formidable task which, at least at the present time, seems better approached in steps: from the basic equations of QCD, through effective field theories, to inter-nucleon interactions and very light nuclei; and further on to the many approaches used to describe nuclear structure, ranging from exact methods such as Green's function Monte Carlo to the shell model and density functional theory. While calculations based on the nucleon-nucleon interaction have achieved quantitative success in reproducing some features of light nuclei, detailed agreement is still lacking for heavier nuclei. This is a problem that is common to the description of other complex systems, such as proteins. In nuclear physics, the development of a comprehensive, predictive theory of complex nuclei remains a key goal. Worldwide, this has driven the recent development of high-quality and multi-faceted radioactive beam facilities, as they allow one to move from a one-dimensional picture where the mass of a nucleus varies, to a two-dimensional picture where both proton and neutron mass numbers vary over a wide range (Fig. 2).

At present, and for the coming decade, the ISAC facility at TRIUMF is a world leader in the emerging technology of radioactive beams, and Canadians have a unique opportunity to make substantive contributions to this field. The number of graduate students in this program has literally exploded over the last few years, and many of the ISAC talks at the 2007 Congress were presented by graduate students. To pick a few examples, Maxime Brodeur (UBC) gave an overview of the TRIUMF Ion Trap for Atomic and Nuclear science (TITAN) program in neutron rich isotopes. TITAN intends to measure the mass of 11 isotopes close to neutron number $N = 32$ and $N = 34$, where drastic changes in nuclear structure are expected. The mass measurements give access to the binding energy of the nucleons, which can directly linked to the underlying shell structure of this many-body quantum mechanical system. James Wong (Guelph) introduced plans for new studies using the deuterated scintillator array for neutron tagging. This will allow studies of fusion-evaporation reactions with neutron-rich nuclei. A particular advantage of using such reactions is that they probe nuclei at moderate-to-high angular momenta. Kyle Leach and Paul Finlay (both of Guelph) presented recent experimental results exploring the properties of superallowed Fermi β-decays using the using the 8π γ-ray spectrometer at TRIUMF. In particular, the ^{62}Ga data are expected to yield a super allowed branching ratio with 10^{-4} precision and will provide stringent tests of the isospin mixing component of the large isospin-symmetry breaking correction for this nucleus.

Recent theoretical advances show strong promise to form a better linkage between the fundamental theory of strong interactions, and the quantitative description of nuclear many-body phenomena. Juris Svenne (Manitoba) presented an algebraic formulation of multi-channel scattering theory that has been developed and applied to the study of nucleon scattering from light nuclei. The procedure allows inclusion of the Pauli principle, even when the target nucleus is described by a collective model. Excellent concordance with data is achieved for total and differential scattering cross sections and analysing powers, and the method has recently been extended to allow the calculation of nuclei away from the line of stability, even particle-unstable nuclei. Byron Jennings (TRIUMF) presented recent developments in nuclear shell model theory involving the renormalization group and the projection operator formalism. The shell model can be cast in the form of a renormalization group procedure, the only significant difference with the usual renormalization procedure being that a discrete basis (usually the harmonic oscillator states) is used rather than a plane-wave basis.

C. What is the role of nuclei in shaping the evolution of the universe?

Primordial nucleosynthesis, nucleosynthesis that occurred during the cooling immediately following the big bang, gave rise to primordial abundances of H, He, and Li. All other chemical elements in the universe were produced as a result of nuclear reactions occurring in stars, during supernova explosions, novae, neutron-star mergers, etc. It is a central goal of physics to explain the origin of matter in the universe, and nuclear astrophysics addresses the many fundamental questions involving nuclear physics issues that remain open. These include: the origin of the elements; the mechanism of core-collapse supernovae; the structure and cooling of neutron stars; the origin, propagation, and interactions of the highest-energy cosmic rays; and the nature of galactic and extra galactic γ -ray sources. Nuclear astrophysics has benefited enormously from progress in astronomical observation modeling, and a new era in nuclear astrophysics has opened with the use of radioactive-beam facilities dedicated to the measurement of nuclear reactions involving short-lived nuclides of relevance to astrophysics. These include measurements of the various nuclear capture processes and the determination of masses, half-lives, and structures of rare nuclei that occur in cataclysmic stellar environments, such as novae or supernova explosions.

The interdisciplinary nature of this field is indicated by the presentation by Andrew Cumming, a theoretical astrophysicist at McGill. He gave an overview of the nuclear physics in Type I *x*-ray bursts and superbursts, which are one way to directly probe the properties of neutron stars. This is because on the surface of an accreting neutron star, helium burns at high temperatures and densities to form carbon, often in a thermally unstable manner, resulting in regular flashes of *x*-rays. Less frequently, a burst which is a thousand-fold brighter and longer occurs, which is due to the burning of the accumulated carbon layer to form heavier isotopes. In the last ten years, long term monitoring of these stars with *x*-ray telescopes has given us new opportunities to study how the burning occurs and to learn about the extreme conditions at the surface of the neutron star. It is gratifying to see the significant progress that has been made in understanding these *x*-ray bursts and the nuclear physics which drives them.

Radioactive nuclides also play an important role in our understanding of stars in their different stages of life, and the different nuclear reaction paths which contribute during these epochs. In many of these processes, the reaction paths follow the shortest-lived nuclides. However, if the lifetime is long enough, the nuclides are likely to survive the nucleosynthesis event and their later observation can be used to trace and understand their origins. Christof Vockenhuber (TRIUMF) presented new work on ^{44}Ti, whose 58.9 year lifetime dictates the light curves of supernovae after the shortest lived nuclides have decayed away. The detection of ^{44}Ti has been identified in Cassiopeia A, the youngest known supernova remnant, by space-based satellites and gives direct observational proof of recent nucleosynthesis. It also provides one of the best tools to understand the complexity of supernova explosions. New results from the DRAGON recoil mass spectrometer include the main production channel via α capture on ^{40}Ca. Rituparna Kanungo (Saint Mary's) presented new results on the decay width of the 4.03 MeV state in ^{19}Ne. This decay width has astrophysical implications because the rate of the ^{15}O(α,γ) ^{19}Ne reaction, which is crucial in the ignition of *x*-ray bursts, depends upon it.

Work also continues with the Canadian Penning Trap (CPT) at Argonne National Lab (USA). Jennifer Fallis (Manitoba) presented new mass measurement results for proton rich isotopes. The existence of elements beyond Fe has classically been thought to result from a combination of three processes, the first two being the well known *r* (rapid) and *s* (slow) processes involving neutron capture, and the third being the *p*-process, which involves proton capture and photodisintegration. However, $^{92;94}$Mo are light nuclei whose observed astrophysical abundances cannot be explained by the *p*-process alone. An ongoing program to reduce the large mass uncertainties that exist for nuclei in the vicinity of ^{92}Pd is expected to help pin down the contribution from the various processes that may contribute to the production of these isotopes.

D. What physics lies beyond the Standard Model?

The forces and symmetries that were in play in the early universe have shaped the cosmos as we know it today. Nuclear physicists have long studied the fundamental symmetries of the weak interaction, and probed the standard model (SM) with very precise low and intermediate-energy experiments. While the SM has proved to be remarkably resilient to these tests, there are a few indications of potential shortcomings in the model. A new generation of experiments, designed to push the limits of discovery and precision, can be grouped in terms of the mysteries they hope to shed light on.

1. The universe has an obvious imbalance of matter and antimatter, but the standard model is unable to explain how this excess has arisen. An essential ingredient in the possible resolution of this enigma is the presence of new interactions that do not behave in the same manner when the direction of time is reversed. Nuclear physicists are seeking to uncover time-asymmetric forces with precision measurements of the properties of the neutron, atoms, and mesons.

2. Another key question is the nature of the "superweak" forces that disappeared from view when the universe cooled. The SM is one of the best-tested theories in physics, but it is believed to be incomplete. Both nuclear and high-energy physicists are continually searching for indications of additional, undiscovered forces that were present in the initial moments after the big bang. High-energy physicists will probe the TeV mass range directly at the LHC, but high-precision experiments at lower energy probe mass scales and parameter spaces not accessible at the high-energy accelerator facilities. Any deviation from the standard model discovered at the LHC, for instance, must be reflected in a corresponding rare interaction at lower energy.

3. Finally, the resolution of the solar and atmospheric neutrino puzzles by SNO and Super-Kamiokande has opened up possibilities for exciting discoveries in the neutrino sector. A key question is the nature of the identified neutrino oscillation. The observation of the extremely rare neutrinoless double beta decay process would revolutionize our understanding of lepton number in the standard model and would determine the mass scale of the neutrino if the nuclear matrix element can be determined sufficiently precisely.

The breadth of the Canadian program in new physics searches was evident in the full day Mini-Symposium on Electroweak Standard Model Tests in Nuclear Physics held at the 2007 Congress. The first session on Leptonic Tests included a talk by Shelley Page (Manitoba) on the future measurements of the proton and electron weak charges via parity-violating elastic scattering at Jefferson Lab. The future electron weak charge measurement will complement ongoing Canadian work on the proton weak charge [presented by Jie Pan (Winnipeg/ Manitoba) in an earlier session], as the two experiments have complementary dependences on new physics beyond the standard model. In particular, the electron weak charge measurement would yield the best determination of $\sin^2\theta_W$ at low energy, and one of the best at any energy scale (see Fig. 3). As a new physics search via the running of the weak mixing angle, the experiment would have unparalleled sensitivity to new parity-violating e - e interactions, probing electron substructure to 29 TeV (95% CL). These measurements will be complemented by parity violation studies in atomic systems planned for TRIUMF-ISAC, such as the work with cold, trapped francium atoms presented at the 2006 Congress.

The Canadian program on superweak interactions was presented in the second session of the symposium on Semi-Leptonic Tests. Michael Gericke (Manitoba) presented the Nab experiment, which will run at the Spallation Neutron Source (SNS), Oak Ridge National Lab (USA). This experiment studies neutron β-decay, one of the most basic processes in nuclear physics. Precise measurements of neutron β-decay correlation parameters offer redundant consistency checks whose failure can be an indication of new physics beyond the SM. The Nab collaboration has developed a method for a simultaneous measurement of the neutron decay parameters a, the neutrino-electron correlation, and b, the Fierz interference term, with a precision of a few parts in 10^3. At the proposed accuracy level, the parameter a can be used to constrain certain left-right symmetric models as well as leptoquark extensions to the standard model. The latter would also be constrained by their measurement of b, which is sensitive to a tensor weak interaction that has often been linked to leptoquarks. The weak interaction mixing (CKM) matrix plays a significant role in nuclear β decay, and experimental tests of the unitarity of this matrix are important probes of possible physics beyond the SM. Dan Melconian (Washington) discussed some of the nuclear β-decay experiments in progress, and the current limits they place on CKM matrix unitarity. These include the UCNA experiment using ultra-cold neutrons at Los Alamos, and an experiment involving ^{32}Ar as a test of the theoretical corrections applied to the super-allowed β decays.

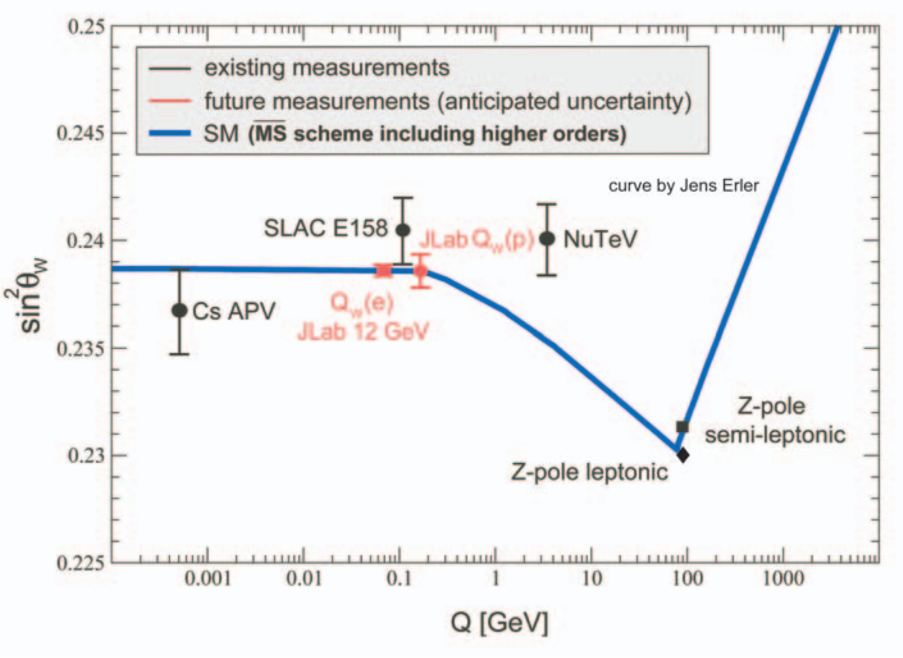

Fig. 3 The running of $\sin^2\theta_W$ in the standard model. The black error bars show the current situation, while the red error bars (arbitrarily positioned on the vertical scale) refer to the anticipated precision of the Qweak measurement and the future 12 GeV Möller scattering measurement at Jefferson Lab. A significant measured deviation from the standard model curve could indicate the onset of new physics at the multi-TeV mass scale.

Neutrino interactions were profiled in both sessions of the symposium, with talks by Scott Oser (UBC) and Chris Jillings (SNOLAB). Neutrinos have simultaneously the strangest and most boring interactions in the standard model, interacting only weakly and with maximal parity violation. but also pointing to its extension in the form of new mass terms and mixing elements needed to describe neutrino oscillation. One of the tools which has been, and will continue to be, used to study neutrino properties is the inverse β-decay of the proton, $\overline{\nu}_e + p \rightarrow n + e^+$. Reines and Cowan first used this reaction to detect neutrinos and the KamLAND experiment uses it to measure the neutrino mixing angle θ_{12}, and the mass splitting Δm^2_{12} . In addition, two new experiments utilizing this reaction are being built to measure the small mixing angle θ_{13} using antineutrinos from reactors. The Double Chooz experiment in France will be sensitive to approximately $\sin^2\theta_{13} > 0.03$ (90% CL), and the Daya Bay experiment near Hong Kong will be sensitive to $\sin^2\theta_{13} > 0.008$ (90% CL). These studies will complement the ongoing neutrino long base line experiments such as the T2K (from Tokai to Kamioka) experiment in Japan, which has a large Canadian participation.

At TRIUMF-ISAC, Canadian researchers also intend to test time-reversal symmetry by searching for permanent electric dipole moments in atomic systems. These studies are complemented by permanent electric dipole moment searches using cold neutrons and by attempts to measure time-reversal violation in the charged kaon sector at KEK and J-PARC in Japan. Chary Rangacharyulu (Saskatchewan) presented plans to search for new physics in the measurement of transverse muon polarization in $K^+ \rightarrow \pi^0 \mu^+ n$ decays at the J-PARC facility under construction. This experiment is being designed as a precision-frontier measurement with the power to constrain the exotic models competitive to the other projects being planned or prepared.

Finally, the ALPHA (Antihydrogen Laser PHysics Apparatus) experiment at CERN will test our knowledge CPT (charge-parity-time reversal) invariance by directly comparing the atomic spectra, and possibly gravitational acceleration, of hydrogen and antihydrogen. This is an international collaboration based at CERN's Antiproton Decelerator facility with the goal of trapping and performing high-precision measurements on antihydrogen. The results from the first run of this experiment were presented by Richard Hydomako (Calgary).

APPLICATIONS

The special properties of the nucleus and the unique technologies developed to pursue nuclear research continue to lead to an impressive array of applications useful to society's needs. The technologies emerging from nuclear physics research play a central role in the arena of human health, and the field of nuclear medicine is a direct descendant of developments in nuclear physics. In recognition of this fact, the DNP jointly organized a session with the Division of Medical and Biological Physics (DMBP) titled “Instrumentation for Nuclear and Medical Physics". Leonid Kurchaninov (TRIUMF) presented the status of an ongoing R&D project on a liquid xenon detector for medical imaging. Liquid xenon is very promising medium for ionizing radiation detection as it is a very bright and fast scintillator, its ionization yield is significant, and it has a high energy resolution which can be improved by weighting ionization and scintillation signals. Because of its short radiation length, liquid xenon detectors are attractive for various fields of experimental physics, such as nuclear physics, astrophysics, astronomy, and nuclear medicine. There were also a number of talks involving elemental analysis of living human subjects. David Chettle (McMaster) gave an overview of the various techniques used. To identify the isotope of an element stored within the body non-invasively, three criteria must be satisfied. An incident probe must reach the storage site, an interaction must produce a signal characteristic of the element in question and the resultant signal must exit the body and be detected. In practice, neutron activation or *x*-ray fluorescence are most widely employed. Some examples include: Cadmium (toxic) can be measured by detecting γ-rays emitted promptly following neutron absorption. The radioactive isotope ^{56}Mn (essential, toxic in excess) is created by neutron absorption and γ-rays emitted following the 2.6 hour half life decay are detected. Lead (toxic) is measured in bone, using γ-rays from the radioisotope ^{109}Cd to excite characteristic *x*-rays.

Nuclear techniques are also essential in providing for the safety and security of our population. Of particular note is the talk by Robert Andrews (Bubble Technology Industries) in the 2006 session held jointly with the Division of Instrumentation and Measurement Physics (DIMP). He showed the impressive work done by his company to identify smuggled nuclear weapons and radiological dispersion devices through radiation interrogation. As nuclear physics pushes to explore new frontiers, new and promising applications of nuclear technology can be expected to continue to emerge.

CONCLUSION

In summary, nuclear physics continues to address exciting and vital scientific questions, and is poised for further great discoveries. As researchers continue to develop new and exciting applications, nuclear physics will continue to become increasingly far-reaching and interdisciplinary in nature. It is essential for governments to continue to make the necessary investments in nuclear physics training and infrastructure, so that society may realize the full benefits of this potential.

Special thanks to Malcolm Butler, Barry Davids, Greg Hackman, Jeff Martin, Pierre Ouimet, and Wim van Oers for their careful reading and helpful comments on this article. It is clear that the DNP program at the Congress was very strong, and I wish to apologize to those speakers whose talk could not be included in this summary article.