PROBING THE QUANTUM UNIVERSE

by Alain Bellerive

This article summarizes the activities encompassed by the Particle Physics Division (PPD) at the 2006 Canadian Association of Physicists (CAP) annual congress that took place at Brock University. The summary is targeted toward the general readership of Physics in Canada as it is meant to be a review for non-experts in the form of a comprehensive overview of the physics research at the subatomic scale. In a way the ultimate goal of particle physics is to establish the link between our Quantum Universe and Cosmology, and the research innovations proposed by the PPD are critical for advancing this mission. The connection between research in particle physics and cosmology has never been closer, with the mysterious dark matter and dark energy which is now known to account for about 95% of the mass of the Universe. The synergy between the upcoming colliders operating at the energy frontier and the underground observatories monitoring weakly interacting messengers are giving us the means to investigate in detail the genesis of massive elementary particles, to study new symmetries, and to discover what dark matter and dark energy actually are, thus creating a breakthrough in our understanding of nature. The effort to understand our natural world is a colossal enterprise and it calls for Canada to promote the development of precise instrumentation at universities across the country and to engage research in the best laboratories around the globe. Precise measuring devices are found at the heart of all forefront scientific investigations. Their development, driven by cutting-edge requirements of basic research, has numerous applications beyond pure physics research and leads to social and economic benefits. This effort is not an easy task and hence represents the very best of what we, physicists, can learn about being human, while providing the otherwise unimaginable insights that illuminate our brief existence here on Earth.

A comprehensive summary of the research topics in subatomic physics and a look at the future challenges of the Particle Physics Division (PPD).

INTRODUCTION

The community of particle physicists in Canada [1] has formed a consensus opinion that the next major facilities that are required to advance the understanding of matter, space, and time are the near term proton-proton Large Hadron Collider (LHC) at the European Laboratory for Particle Physics (CERN) near Geneva, the neutrino beam at the KEK High Energy Accelerator Research Organization in Japan, the Deep Underground Laboratory in Sudbury (SNOLAB), and the longer term International Linear Collider (ILC). Those projects are planning to answer the key open questions at the forefront of research in particle physics: the origin of mass, the composition of our Universe, and the understanding of elementary particle properties. The on-going Canadian participation in CLEO-c, ZEUS, D0 and CDF projects are paving the road for understanding the physics awaiting our community at the LHC. The knowledge gained by the future ILC experiments and the upcoming LHC experiments is complementary since both facilities are needed to develop a more complete theory of fundamental particles and interactions. The study of particle properties and the probable discovery of the constituents of dark matter at accelerator complexes is tightly coupled to direct investigation of weakly interacting particles with underground detectors to be located in a deep and ultra-clean environment at the newly funded SNOLAB. Neutrino beam experiments will also provide new insights about particle mixing in the lepton sector; which are complementary to the ongoing investigation in the quark sector by the BaBar experimental programs at the high-luminosity B-Factory at the Stanford Linear Accelerator Center (SLAC). The TWIST experiment at Canada's National Laboratory for Nuclear and Particle Physics (TRIUMF) strengthens the elucidation of the weak interaction by studying the decay of polarized muons; while the top-cited Sudbury Neutrino Observatory (SNO) is probing how the Sun is producing neutrinos.

Astronomical observations are complementary to the quest of probing matter at the subatomic scale. As most of the galaxies seem to be filled with dark matter and dark energy, the study of fluctuations in the cosmic microwave background together with data from supernova and galaxy cluster surveys might confirm the original concept of Einstein's cosmological constant, in which empty space is filled with a mysterious energy that increases as the universe expands. Furthermore annihilation of dark matter particles might be detected in high-energy gamma ray telescopes such as the PPD project VERITAS. In an attempt to reveal the ultimate link between the cosmos and the subatomic world, particle physicists will hunt dark matter particles at accelerators and underground experiments in order to investigate their quantum properties and consequently understand the profound nature of the universe.

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For non-experts, the previous two paragraphs are only jargon and acronyms. Let's pause and see what it all means and let's try to put all of this into perspective. Everybody knows the irony of quantum mechanics. Particle microscopes required to probe the subatomic scale are huge experimental apparatus that physicists like to call gothic cathedrals of modern time for the hunt of the "God" particle. To add to this grandiose scheme, particle physicists are sometime a little bit arrogant with their multi-million international large scale projects. Is this all vanity or is it following a logical path for the ultimate truth?

THE STANDARD MODEL

Throughout human history, scientific theories and experiments of increasing power and sophistication have addressed the basic questions about our Universe. The resulting knowledge has led to revolutionary insights into the nature of the world around us. In the last 40 years, physicists have achieved a profound understanding of subatomic physics with a simple and comprehensive framework that explains the hundreds of composite particles in nature together with the complex reactions taking place between them. In the modern study of the fundamental constituents of matter and their interactions, the Standard Model succeeds to explain all the phenomena of particle physics in terms of three distinct types of elementary particles. The first two are the leptons and the quarks, both spin ½ fermions. The other is the gauge bosons, carriers of four distinct types of fundamental force: gravity, electromagnetism as well as the weak and strong interactions.

Researchers have subjected the Standard Model to countless experimental tests; and, again and again, its predictions have held true. The series of experimental and theoretical breakthroughs that combined to produce the Standard Model can truly be celebrated as one of the great scientific triumphs of the past century. Consequently, one of the most pressing questions in particle physics at this time has to do with the way the electromagnetic and weak forces, which are unified at very high energies, appear as distinct forces at low energies. The breaking of the electroweak symmetry is explained in the Standard Model by the Higgs mechanism, which predicts the existence of a fundamental so-called God particle, known as the Higgs boson. Within the model, this particle is responsible for the mass of all matter in the Universe. Understanding this unknown Universe requires powerful tools. Particle accelerators enable the search at the quantum level; while astrophysical observations complement the exploration at a large scale.

Since Einstein, physicists have sought a unified theory to explain all the fundamental forces and particles in our Universe. The result is a stunningly successful theory that reduces the complexity of microscopic physics to a set of concise laws. But these same quantum ideas fail when applied to cosmic physics. Some fundamental piece is missing; the origin of mass and gravity, as well as dark matter and dark energy likely have quantum explanations. A new theoretical vision is required, one that embraces the Standard Model and general relativity, while resolving the mystery of dark energy. Current and future experiments around the world give us the capability to address this well-defined set of questions about the basic physical laws that govern the interaction between elementary particles. Those questions, at the same time eminently familiar and profoundly revolutionary, define the path for particle physics in the upcoming decades.

ZEUS AND ITS DESCRIPTION OF PARTICLE BAGS

The very high energy electrons produced by the Hadron Electron Ring Accelerator (HERA) at the German Electron Synchroton (DESY) offers the possibility to probe deep inside the proton and to study the structure of its constituents, the quarks and gluons. Following Heisenberg's uncertainty relation, an investigation at the smallest scale is only possible with high momentum electron impacts on the proton. The ZEUS detector can probe 10^{-16} cm for a transverse momentum of $q^2 = 40{,}000\ \mathrm{GeV}^2$, which is a factor 1,000 smaller than the proton radius. With this resolving power, numerous physical phenomena can be studied, such as possible substructures of quarks and electrons, neutral and charged current processes mediated by the weak interaction, tests of strong forces via quantum chromodynamics (QCD), and searches for new particles. Ultimately, HERA provides a method of describing the properties of a system of confined quarks and gluons (*i.e.* partons) with the famous bag model and the associated Parton Density Functions (PDFs). This is very important for the next phase of physics exploration at the LHC. The ZEUS Collaboration reported at CAP06 [2] preliminary cross-sections that can be fitted simultaneously for the mass of the charged mediator of the weak interaction (*i.e.* the W boson) as well as PDF parameters. The fit leads an impressive value of $M_W = 79.10 \pm 0.77$ (stat) ± 0.99 (syst) GeV/c^2 and unprecedented precision over a wide range of transverse momentum for the PDF parameters. ZEUS is scheduled to acquire data until 2007.

TWIST & SHOOT

TWIST is an experiment at TRIUMF in Vancouver. It is designed to measure the decay distributions of polarized muons to high precision. The muon is a particle that appears identical to an electron in all regards except that it is heavier. Physicists of the TWIST Collaboration are investigating differential energy and angular distribution with a precision of one part in 10,000, allowing a determination of the parameters of the Standard Model which characterize the weak muon decay to a precision 2 to 10 times better than previously achieved. In the Standard Model, generation-changing transitions between quarks and leptons are allowed via a Vector-Axial (V-A) weak charged current. The goal of TWIST is to better understand the V-A assymmetry of the weak interaction with the measurement of the parameter $P_\mu\xi$. A deviation from unity of $P_\mu\xi$ would be clear evidence of new physics. The most recent TWIST analysis yields $P_\mu\xi = 1.0003 \pm 0.0006$ (stat) ± 0.0038 (syst) [2]. The most challenging aspect of such a high precision endeavor is the systematic uncertainties associated with depolarization of the muons.

CHARMING THIS CLEO DETECTOR

The CLEO-c detector located on the campus of Cornell University in Ithaca, NY, is a dedicated program for the study of the charm quark. The physics of open-charm production is critical to the overall subatomic physics program as it probes the decay product of heavier quarks such as the beauty and top quarks. Overall, CLEO-c will help elucidate the underlying strong-interaction dynamics that currently limit our understanding of the weak interaction responsible for the decay of heavy flavored hadrons, will precisely measure the exclusive branching ratios of charmed mesons, and will study a vast number of new states [2]. Thus, making charm physics extremely relevant for the physics program at BaBar and the Tevatron.

BABAR AND ITS BEAUTY FACTORY

For each particle in nature there is an equivalent anti-particle with opposite quantum numbers. The Big-Bang created an equal amount of particles and anti-particles; but physical observations do not account for the existence of large clusters of anti-matter in the Universe. BaBar is an experiment located at SLAC near Stanford University in California. The goal of the experiment is to study the violation of charge and parity (CP) symmetry in the decays of B mesons. B mesons are made of one beauty quark and one up or down quark. To investigate CP violation, the PEP-II accelerator shoots a 9.1 GeV electron beam against a 3 GeV positron beam. Quarks can never appear as free particles in a final state. In e^+e^- annihilation, the quarks produced are initially free, but as they separate to a distance of about 1 fermi the increasing strength of the strong interaction converts their kinetic energy into additional quarks which combine to form mesons. This process is called fragmentation. Near 10 GeV, the beam energy is sufficient for the production of a beauty plus anti-beauty state called the Υ(4S). Since CP violation manifests itself as different behavior between particles and anti-particles, the two colliding beams are the heart of the SLAC B-factory which produces copious amounts of Υ(4S) mesons that decay into equal numbers of B and anti-B mesons. The basic requirement of the BaBar detector for the extraction of the CP asymmetry is to reconstruct the distance between the decay products of the B and anti-B with a precision an order of magnitude better than 250 μm.

In the Standard Model, the quark weak decays $q \rightarrow W q'$ have strengths that depend on the flavour of the quarks involved. The coupling at the W boson vertex is proportional to a complex number $V_{qq'}$ which lead to possible violation of the CP symmetry. Besides its importance in understanding the structure of the weak interaction, CP asymmetry is of paramount importance to explain the predominance of matter over antimatter in the Universe. In the literature the amount of CP violation in the B meson sector is described by three angles (β, α, and γ) that constrain a unitarity triangle. The unitarity triangle is a simple geometrical representation of the quark mixing matrix that describes quark transitions.

In 2001, BaBar physicists found a striking difference between matter and antimatter and reported a non-zero value of one of the angles of the unitary triangle. This confirmed CP violation in the neutral B meson sector. At CAP06, improved measurements of the unitary triangle angles were reported [2]. The amplitude of the CP asymmetry charecterised by the angle β, as derived from decay-time distributions from events in which one B^0 or anti-B^0 meson is fully reconstructed in a final state containing a charmonium meson, leads to $\sin 2\beta = 0.722 \pm 0.040$ (stat) ± 0.023 (syst). Furthermore, an independent challenging analysis that relies on the precise reconstruction of $\pi^0 \rightarrow \gamma\gamma$ in $B^0 \rightarrow J/\psi\pi^0$ decays yields $\sin 2\beta = 0.68 \pm 0.30$ (stat) ± 0.04 (syst), which is consistent with the world average of $\sin 2\beta = 0.69 \pm 0.03$. New results from BaBar allow for preliminary determinations of $\alpha = (100.2 + 15.0 - 8.8)^o$ and $\gamma = (67 \pm 33)^o$. Improved results and a large number of rare decay studies are expected in the next two years of data taking as PEP-II will most likely terminate its successful scientific program by the end of 2008.

SUDBURY AND ITS SOLAR NEUTRINOS

While the BaBar Collaboration was investigating CP violation and quark mixing, the Sudbury Neutrino Observatory (SNO) has solved a 30-year old mystery by showing that neutrinos from the Sun change species and mix on their journey to the Earth. The deficit of solar neutrinos with our expectations based on laboratory measurements, known as the solar neutrino problem, has remained one of the outstanding problems in basic physics. It appeared inescapable that either our understanding of the energy producing processes in the Sun is seriously defective, or neutrinos, one of the most abundant particles in nature, have important properties which have yet to be identified. It is known that neutrinos, like quarks, exist in three different types corresponding to the three known charged leptons, the electron, muon and tau particles. The solar-neutrino detectors in operation prior to SNO were sensitive mainly to the electron neutrino type while the use of heavy water in SNO allows the flux of all three to be precisely measured. Neutrinos from ^8B decay in the Sun ($^8B \rightarrow {}^8Be\ e^+ \nu_e$) are observed in SNO via Čerenkov radiation. Only electron neutrinos can interact through a weak charged-current interaction; while all neutrinos can interact through a weak neutral-current reaction. The determination of these reaction rates is critical in determining if neutrinos mix and oscillate. In fact they do! In 2002, the SNO Collaboration reported direct evidence of solar neutrino oscillation. The first data from SNO had a huge impact in the field of particle astrophysics because neutrinos must have mass to oscillate. Neutrinos were postulated by Pauli in 1931 and incorporated as massless particles within the Standard Model. Hence the SNO result reveals that the minimal Standard Model is incomplete and calls for modifications within the theoretical framework of subatomic physics.

After 30 years of hard labor from the nuclear and particle physics community, the solar neutrino problem at SNO is now becoming an industry for precise measurements of matter induced solar neutrino oscillation parameters and an exploration platform for rare physics phenomena. At the St. Catharine's congress [2], SNO presented in grande-première new searches for rare hep solar neutrinos ($^3He + p \rightarrow {}^4He\ \ e^+ \nu_e$) and Diffuse Supernova Neutrino Background (DSNB). Under the assumption of solar neutrino oscillation, the upper limit set at the 90% confidence level (C.L.) on the hep flux is 2.3×10^4 cm^{-2}s^{-1}, with an expectation of $(8.0 \pm 1.3) \times 10^3$ cm^{-2}s^{-1} based on the Solar Standard Model. The upper limit on the DSNB flux at the 90% C.L. is 70 cm^{-2}s^{-1}, while the theoretical expectations are in the range of 0.2–1.5 cm^{-2}s^{-1}. The SNO hep and DSNB limits are the world's best results as they are 6.5 and 100 times better than previous limits set by the Super-Kamiokande and Mont-Blanc experiments, respectively.

THE ONGOING CDF AND D0 PROJECTS

The Tevatron accelerator at the Fermi National Accelerator Laboratory (FNAL), near Chicago, collides protons and anti-protons every 396 nsec in the heart of two multi-purpose spectrometers known as the CDF and D0 experiments. Inside the six-kilometer-long underground ring, each beam travels at an energy of 980 GeV; making Fermilab's Tevatron the most powerful accelerator in the world. At the beginning of 1995, both CDF and D0 simultaneously submitted papers announcing the discovery of the heaviest elementary particle known to exist: the top quark. The top quark is as heavy as a gold atom, yet its mass is confined to a volume much smaller than a single proton. The primary performance of the CDF and D0 detectors is judged by their efficiency to reconstruct top and anti-top pairs which then decay to two W bosons and two beauty quarks. Four years ago, the Tevatron collider and the CDF/D0 experiments went through a major upgrade. After hard work from the FNAL accelerator division, the revamped machine is now producing the Run II data set at the design rate. The most precise individual preliminary results [2] for M_{top} from Run II is now 173.4 ± 2.8 GeV/c^2 by CDF and 170.6 ± 4.6 GeV/c^2 by D0; which is much more precise than previous Run I measurements. This lead to a phenomenal world-average of 172.5 ± 2.3 GeV/c^2 that already exceeds the original precision goal of 3 GeV/c^2 set before Run II started.

The Tevatron is a not only a factory for the production of top quarks, but also for the production of beauty quarks. The challenge in the multi-hadronic environment at the Tevatron is to identify and isolate the topology associated with an event containing beauty hadrons. While the detailed investigation of B^0 and anti-B^0 oscillation is the bread-and-butter of the BaBar experiment, the Tevatron is complementary to the B-Factories since it can also produce the neutral B_s meson composed of a beauty anti-quark and a strange quark. The B_s meson is expected to mix just like his brother the B meson, but at a much higher rate, making the oscillation signal very faint. The CDF Collaboration reported discovery of B_s and anti-B_s mixing with only a 0.2% probability that the data could randomly fluctuate to mimic such a signature. The B_s mixing is characterized by the mass difference Δm_s expressed in unit of time. According to CDF it yields a value of 17.31 +0.33 –0.18 (stat) ± 0.07 (syst) psec^{-1}. This value is consistent with a 90% confidence interval of 17 psec^{-1} < Δm_s < 21 psec^{-1} set by D0 before the claim of the CDF discovery. All of those new results [2] compare well with the Standard Model expectation of 16.7 psec^{-1} < Δm_s < 25.4 psec^{-1}.

While all the quarks and leptons as well as the gauge bosons responsible for the electroweak and strong interactions have been discovered, the Higgs boson is still missing. Fortunately, the Tevatron is now cranking out data at a prodigious rate and the CDF and D0 experimenters are optimistic that, if nature cooperates, they might have a shot at seeing the Higgs. The Standard Model does not predict the mass of the Higgs boson, but its parameters are so tightly interconnected that precise mass measurements of the W boson and the top quark masses suggest that the Higgs is light and possibly within Tevatron's grasp if its mass is less than 125 GeV/c^2… and if the machine runs through 2009 as planned. The hunt for God's particle is raging in the U.S. until the LHC turns on in Europe.

CANADA'S FLAGSHIP PROJECT: THE ATLAS EXPERIMENT AT THE LHC

Particle physics is at an extraordinary epoch. As we enter the 21st century, particle beams and cosmic radiation are not simply producing new particles to be catalogued. Rather, those particles are messengers telling a profound story. The role of the PPD is to listen to the story and translate it into the language of human knowledge and, more importantly, scientific understanding of the subatomic world. The Large Hadron Collider (LHC) is the next step in a voyage of investigation which began in 1896 when H. Becquerel, with P. Curie and M. Curie, investigated radioactivity and in 1897 when J.J. Thompson discovered the electron. More than a century after the discovery of the first elementary particles, physicists are now on the verge of explaining the origin of their mass and the basic forces that shape our Universe.

The LHC at CERN will soon begin exploring physics at the TeV scale. With its 27 km circumference, the accelerator will be the largest superconducting installation in the world and will collide 7,000 GeV proton beams at a rate of 800 million times a second. The benchmark of the LHC physics program involves an intense search for subatomic clues that reveal the character of the Higgs mechanism. The combined fit of all the high precision electroweak data to the Standard Model predicts a light Higgs boson with an upper mass limit of 186 GeV/c^2 at the 95% confidence level. Combining the results on the direct searches for the Higgs boson at LEP leads to the

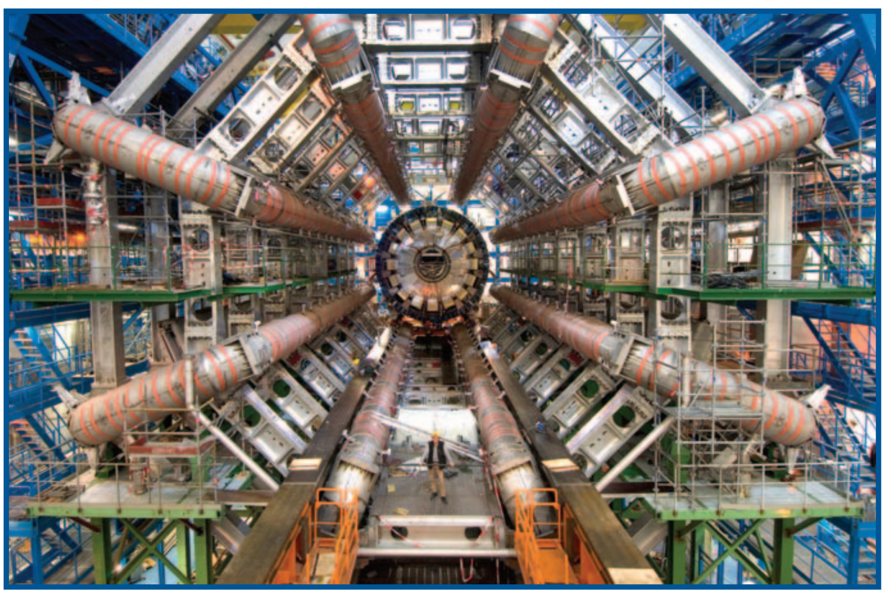

Fig. 1 ATLAS detector under construction, October 2005.

conclusion that the Standard-Model Higgs boson must be heavier than 114.4 GeV/c^2 at the 95% confidence level. The current Tevatron run may extend the reach to 125 GeV/c^2 or more. The LHC experiments will extend the discovery reach to the highest mass allowed for the Higgs boson in the Standard Model. Another particularly intriguing possibility is the observation of supersymmetry at the LHC. The lightest supersymmetric particle (sparticle) is a natural candidate for dark matter. By determining the complete spectrum of sparticles and their couplings, the relic density of this dark matter candidate can be calculated, and compared with astronomical observations. This would either confirm the origin of dark matter, or possibly indicate that there is more than one source of dark matter.

Canada [2] is strongly involved in the ATLAS experiment, one of the four LHC detectors. The 7,000 ton, 46 meter-long, and 25 meter-high cylindrical detector is set to seek the Higgs phenomena, supersymmetry or even hidden extra dimensions. ATLAS is one of the largest collaborative efforts ever attempted in the physical sciences. There are 1800 physicists (including 400 students) participating from more than 150 universities and laboratories in 35 countries. The purpose of ATLAS is to provide information about the collision products for each proton-proton collision. That information must be obtained and analyzed very rapidly as only 10 to 100 of the billion collisions that occur each second must be flagged as potentially interesting and recorded for further study, while all the others are rejected. ATLAS will produce several petabytes of raw data per year and will rely heavily on pioneer work on Grid computing technology developed by high energy physicists. All key objectives for the construction and operation of the LHC machines and the ATLAS experiment have been reached and the plan is to have first collisions by the end of 2007.

T2K IS THE NEW TUNE FOR NEUTRINO OSCILLATION

Unlike the quark sector, where the mixing effects are small, the lepton sector exhibits large mixing. Hence, neutrino masses and mixing may play significant roles in determining structure formation in the early Universe as well as supernovae dynamics and the creation of matter. The coming decade will be exciting with neutrino physics helping to delineate the new Standard Model that will include neutrino masses and oscillations.

The Tokai to Kamioka (T2K) experiment is a second generation long-baseline neutrino-oscillation experiment. This will lead to precision measurements of the leptonic mixing matrix, determination of neutrino masses, and investigation of CP and CPT properties in the lepton sector. An artificial neutrino beam generated in the Tokai JHF 50 GeV high-intensity proton accelerator is shot towards the 50 kton water Cherenkov detector, Super-Kamiokande, which is located about 1000 m underground in the Kamioka mine and is 295 km away from Tokai. The Canadian T2K group is designing and building the tracker for the near detector [2]. The tracker's main goal is to measure the initial flux of neutrinos produced in the beam. Neutrino oscillation scenarios are then probed by comparing the initial flux with the reconstructed events at the far detector (*i.e.* Super-Kamiokande). The construction is under way, commissioning will take place in 2008, and physics data are expected in 2009.

THE UPCOMING UNDERGROUND SUDBURY LABORATORY (SNOLAB)

The SNOLAB facility will provide infrastructure for exciting new measurements in particle astrophysics which can only be carried out in deep ultra-low radioactivity conditions. The 2 km of rock over-burden at the site provides 6010 m of water equivalent of shielding from cosmic rays and offers a unique environment for the search of neutrinoless double beta decay and dark matter; but also to continue the study of low energy solar neutrinos (*e.g.* SNO+) and Supernova. Excavation has begun and is expected to be completed in 2006. Space for experiments will become available in 2007.

The search for neutrinoless double beta decay is a pressing and challenging task facing particle physics today. With the demonstration by Super-Kamiokande, SNO, and reactor-based neutrino experiments that neutrino oscillations occur with large mixing amplitudes, this implies that neutrinos must possess mass. The oscillation measurements determine mass-squared differences among the neutrino mass states but they do not determine an absolute mass scale. The measurement of neutrinoless double beta decay would provide unique information about the absolute mass values for neutrinos. There are several efforts world-wide into the search for neutrinoless double beta decay. The scale of these experiments is such that only a small number will actually proceed to full scale and these selected experiments will need the combined efforts of the world community if they are to succeed. Rather than initiate another project, the Canadian physicists have opted to join two of the most promising existing teams, Majorana and the Enriched Xenon Observatory (EXO).

Current models explaining the evolution of the Universe and measurements of the various components of its constitution, all have in common that an appreciable contribution to its mass is non-luminous and non-baryonic, and that a large fraction is cold dark matter in the form of non-relativistic massive particles. Accelerator experiments have explored up to now only a small range of masses of possible candidate particles. Many competing cold dark matter detector experiments have started restricting cross-sections and masses for various candidates. They all leave room for an interpretation in terms of weakly interacting massive particles (WIMPs), one of which, the supersymmetric neutralino, remains one of the best candidates.

The interaction of WIMPs with ordinary matter can be either coherent or spin-dependent. The detection reaction would be elastic scattering off a detector nucleus and the nuclear recoil energy would be the measurable quantity. Progress on two projects was summarized at Brock University: DEAP and PICASSO. DEAP relies on liquid argon as an active medium; while PICASSO is based on the phase transition of a superheated C_4F_{10} droplet detector. The PICASSO experiment reported at CAP06 [2] limits for the existence of cold dark matter WIMPs interacting via spin-dependent interactions with nuclei. The prototype experiment was installed at the SNO depth and no evidence for a WIMP signal was found. Expected improved limits with a larger detector were reported and suggest a very promising R&D program at SNOLAB.

FUTURE AT THE ENERGY FRONTIER

Mankind's quest to understand nature at its deepest level will not end with the discoveries at the LHC. Historically, the most striking progress in particle physics has come from combining results from proton accelerators, like the Tevatron at FNAL, with results from electron accelerators, like the former Large Electron-Positron (LEP) collider at CERN. The global particle physics community is now proposing the e^+e^- ILC that will extend discoveries and answer questions that will arise from proton-proton collisions at the LHC. The past few years have seen the emergence of a world consensus for the construction of an e^+e^- linear collider with centre-of-mass energy of 500 GeV (upgradeable to 1 TeV) as the highest priority next accelerator at the energy frontier. Particle physicists are convinced thatfa the ILC is essential to advance the field and a strong case has been made to construct an international ILC in time to have a significant period of concurrent running with the LHC. Although the Higgs particle is expected to be discovered before the future ILC begins operation, a complete knowledge of its properties is judged to be crucial by the PPD Long Range Plan [1] to determine if it is the particle predicted by the minimal Standard Model or new physics beyond human imagination.

CONCLUSION

The developments summarized in this article are the main projects under the umbrella of the Particle Physics Division (PPD). All of them will, one way or another, enable breakthroughs in basic science by addressing critical questions in subatomic physics. It is also relevant to say that the physics communities often have to form international partnerships to build cutting-edge experiments and accomplish the goals set by advancement in science. It is very much the case in particle physics as no researcher or nation could afford it otherwise. Big science and innovative technology, such as applications of particle detectors to treatment and diagnostic medicine, the World Wide Web invented at CERN, superconductive magnet research pioneered at FNAL, fast electronics spin-off for the industry, innovation in networking and Grid computing, are often viewed as the engine of why we do physics. In reality the general public may wonder whether such scientific largesse should be afforded to a minority such as physicists. An attempt to justify the amount of money spend in physics in the context of human suffering will always fall short, but in general the physics community of all fields really have fundamental questions to address and need to rely on large infrastructure. So, is research in particle physics all vanity or is it following a logical path for the ultimate truth? In conclusion, I think all areas of physics are trying to explain our existence because science is a vital part of who we are and it must involve an intense search for clues that reveal the character of the building blocks of our World.

ACKNOWLEDGEMENT

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NEWS / INFORMATION

TRIUMF SUCCESSFULLY COMMISSIONS CANADA'S FIRST SUPERCONDUCTING LINEAR PARTICLE ACCELERATOR

(Vancouver, B.C.), May 17, 2006

The TRIUMF national laboratory has achieved a new milestone by successfully commissioning a superconducting linear accelerator (linac) at its subatomic physics complex situated on the UBC campus in Vancouver. The superconducting linac will accelerate rare isotopes created by the TRIUMF cyclotron beam. This development positions TRIUMF as the world's premier facility for the study of nuclear physics and astrophysics, addressing fundamental questions of the universe's existence.

Particle accelerators are used to investigate many areas of science ranging from medical science to study of the evolution of the universe. Since 1968, with the construction of the world's largest cyclotron accelerator, the TRIUMF laboratory has been a leader in accelerator technology. Currently TRIUMF operates seven accelerators of various sizes, each based on one of three different technologies operating at room temperature: cyclotron, radio frequency quadrupole, and the drift tube linac. TRIUMF has been a world leader in using these accelerators to produce some of the most exotic shortlived atoms in the universe in order to address a wide range of scientific questions, as well as to produce such radioisotopes for use in medical diagnostics worldwide.

TRIUMF Science Director JeanMichel Poutissou congratulated the staff associated with the project for their hard work, stating that "this is a tremendous achievement which brings new technology to BC and a unique research tool for Canadian researchers and for the nuclear physics research community worldwide."

Over the past four years, TRIUMF has built on its expertise at accelerating shortlived exotic isotopes by developing and constructing a new type of linac based on superconducting radiofrequency cavities.

The 20 superconducting accelerator cavities are cooled to 269O C (just 4O above absolute zero) with liquid helium. This technology has been used at other laboratories for other applications, but this is the first time it has been developed for accelerating shortlived exotic isotope beams in Canada.

This rare isotope superconducting accelerator, called ISACII, is being built in two stages. The first stage is now complete and successfully accelerated its first beam in April 2006. The final stages are scheduled to be constructed during the next four years. Along with the ISACI facility already in operation at TRIUMF, the new ISACII accelerator will be used to accelerate shortlived exotic isotopes produced by TRIUMF's large cyclotron.

Professor Brad Sherrill, University Distinguished Professor of Physics at Michigan State University, and Chair of the American Physical Society Division of Nuclear Physics, said "Production, separation, and acceleration of atoms that live for only a few seconds or less is a very difficult task. The group at TRIUMF has done an outstanding job at advancing this science and it is exciting to hear that the new ISACII facility has reached a key milestone. The new capabilities will make TRIUMF the best place in the world to do experiments with accelerated beams of exotic isotopes."

These developments were made possible by generous financial support from the Federal Government of Canada through the National Research Council of Canada, and from the B.C. Provincial Government.