RECENT ACHIEVEMENTS IN MESON SCIENCES AT TRIUMF

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1. Introduction

It can be argued that the term "Meson Sciences" embraces all of the physics pursued at the meson factories. Although these factories provide several quite different hadronic probes, the energy and distance scales for each are such that mesonic interactions are central to the physics. Further, the muons continue to intrude into the physics as inextricably as they did at the time of Yukawa's discovery whose anniversary we are celebrating. The physics continues to be an exciting mix.

In the preceding paper, Louis Rosen has painted a complete portrait of the development of LAMPF, one of the world's meson factories. In the next paper Jean-Pierre Blaser gives a full account of SIN and especially of its program of pion therapy, one of the very important and promising spin-offs of the meson factories now being actively pursued at his meson factory (SIN) and also at ours. In my paper I shall give a selection of recent TRIUMF experiments intended to illustrate how Meson Science as a whole is flourishing at the meson factories.

The meson factories differ from each other in their facilities as much as in their science. I shall therefore give a brief description of the TRIUMF cyclotron and its experimental facilities as a basis for the discussion of the science.

The measure of Yukawa's immense contribution lies not in the permanence of his specific ideas about the mesons as particles or about their role in the strong interactions but rather in the fertility of these ideas for the subsequent evolution of the field. The initial idea of the Yukawa force, the cornerstone of nuclear physics, has evolved into the present Standard Model in which the strong interaction pertains to quarks and is carried by gluons. The mesons are now merely messy composites made of a quark-antiquark pair. In spite of the tremendous changes in the picture, we learn at this symposium of how the essence of Yukawa's ideas about the meson field for the nuclear force was really the beginning of the subject of particle physics and still pervades our thinking.

Similarly the science program of the meson factories should be judged not in their conformity to initial expectations but rather in how they have been able to respond to the rapid evolution of ideas in the field. As I shall try to illustrate the TRIUMF experimental program, like those of its sister meson factories, now addresses most of the important physics questions raised by the Standard Model for quarks and leptons and their interactions. Intermediate energy beams of protons, neutrons, muons, and pions are the tools used for this purpose. It is a huge and varied feast complementary to the exciting physics at the energy frontier pursued at the colliders.

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2. The TRIUMF Facility

As shown on Fig. 1, the TRIUMF facility is now a complex set of primary and secondary beam lines based on a negative ion cyclotron. LAMPF, SIN, and TRIUMF all achieve very intense intermediate energy proton beams with very different accelerators.

It is amusing to note that although there was a thirty year gestation period between Yukawa's original concept of the meson and the advent of the ideas and proposals for the meson factories, when the time for the meson factories had arrived, three such very different machines emerged almost simultaneously. Each of these facilities capitalizes on its own special features. The LAMPF linac has produced the most intense and energetic proton beams but the primary beam is pulsed. For many coincidence experiments the 100% duty factor of TRIUMF and SIN cyclotrons are crucial. SIN's ring cyclotron accelerates protons and has a fixed primary beam energy of 590 MeV. The TRIUMF cyclotron accelerates negative hydrogen ions and has an extracted proton beam variable in energy between 180 and 520 MeV.

The TRIUMF cyclotron depicted on Fig. 1 was the brainchild of J.R. Richardson¹ and is, in many ways, one of the most novel and versatile accelerators ever built. It combines two important ideas. First, the spiral-ridge sector-focused magnet allows cw acceleration at a common frequency all the way from the non-relativistic injection energy of 0.3 MeV to the final relativistic extraction energy of 520 MeV. The use of negative ions allows easy and efficient extraction, by means of a thin stripping foil at the appropriate radius, and also variable energy through movement of the foil. An added bonus of the negative-ion acceleration is the possibility of simultaneous extracted beams through partial extraction with several stripping foils. The price one pays for these advantages pertains to the fragility of the negative ions. Very good vacuum is required to reduce stripping by residual gases and the main magnet is uncomfortably large (20 metres in diameter) to achieve the low magnet fields which mitigate the electric stripping losses (from $\vec{v} \times \vec{B}$ forces) of the negative ions. The experiments made possible by TRIUMF's special features have easily justified the extra complexity of the cyclotron.

We see then, in Fig. 1, two or more simultaneous extracted beams of protons. In the proton hall the variable-energy extracted proton beam is used or, alternatively, knock-on neutrons produced by this beam from an appropriate target. In the meson hall the primary proton beam (1A) is intercepted by two meson production targets (T1 & T2) and a total of six secondary beam lines for pions and muons emerge from these. Thus the experimental program normally involves protons, neutrons, pions and muons, and many different experiments receiving beam simultaneously.

The experimental program described below takes advantage of many of TRIUMF's special features. TRIUMF has been a leader in the development of intense polarized beams and combined with the energy variability it then possesses high quality nucleon beams over a wide and interesting

energy interval, a capability not matched anywhere else in the world. Also, in the proton hall these nucleon beams have been complemented with a large, good-resolution (~100 keV) spectrometer. In the meson hall we take advantage, like SIN, of the cw primary beam to provide some excellent low energy muon and pion channels. There has been a very active recent program at TRIUMF in building new beam secondary lines (M13 and M15) and rebuilding old ones (M20 and M11) partly in response to the very great interest in muons and partly to take advantage of intense low energy muon sources through pion decay in and around the production targets. In the rapidly changing field of subatomic physics it is difficult to overestimate the importance of beam line improvement.

3. Experiments in the Proton Hall

There is so much more to the nucleon-nucleon interaction than the saturation property - or short-range - which initially gave rise to the Yukawa force. The most important program in the early years of TRIUMF was an accurate survey² of the properties of the nucleon-nucleon force from 180-520 MeV, the important energy interval which includes the opening of the pion production channel. Throughout this energy interval the various spin correlation parameters were measured for both p,p (isospin 1) and n,p (isospin 0 and 1) channels. This data constituted a step-function increase in our knowledge of the nucleon-nucleon force. It continues to provide a stringent testing ground for theories which now use a variety of frameworks: traditional expansions of Yukawa's ideas now involving a multitude of exchange mesons and bosons; bag-models attempting phenomenologically to accommodate some fundamental symmetries and also quark confinement and QCD models tackling head on a theory which is both compelling and almost intractable. Some look wistfully backward at a simpler era when single pion exchange and a hard core described everything we knew. Others hope for miracles (for example, sharp dibaryon resonances) which may simplify future descriptions. At present, much remains to be done.

An important recent example of the effort to understand the fundamental aspects of the nucleon-nucleon force is the charge-symmetry experiment just completed by Wim van Oers³ and his colleagues at TRIUMF. Compared to the completed nucleon-nucleon survey, this is a second generation experiment in which one looks for very small effects (~10⁻³) in the nuclear force if one changes all neutrons into protons and vice-versa.

In this experiment the scattering of polarized protons from unpolarized neutrons was compared with the charge symmetry inverse, the scattering of polarized neutrons from unpolarized protons. The asymmetry parameter in such scatterings crosses through zero at a certain angle (depending on the energy) and one looks for breakdown of charge symmetry causing very small differences in the crossing angle. In the experimental set up, Fig. 2, crossing angle differences as small as one-twentieth of a degree were looked for and asymmetries were measured to 0.1%. This level of accuracy required high intensity polarized beams (approaching 1μA on target) and a frozen-spin target of

considerable volume. Such an experiment produces roomful of data tapes. Six months after final data runs, the initial analysis³ (July, 1985) of part of the data produced a finite result of $0.13 \pm 0.07^\circ$ difference in the crossing angle. For the final analysis enough data exists to reduce the error to $\pm 0.06^\circ$. This is the first definite measurement of charge-symmetry breaking and it is free of any Coulomb distortions for its interpretation. In the analysis of Cheng, Henley, and Miller⁴, such charge-symmetry breaking effects in nucleon-nucleon scattering can arise from direct electromagnetic effects, from meson mixing (ρ - ω), and from the nucleon mass difference.

Further second-generation experiments are planned to measure parity-violation in the nucleon-nucleon force at TRIUMF energies and also, possibly, to measure the energy-dependence of charge-symmetry breaking using a much higher intensity optically-pumped polarized ion source now under development.

Again in the proton hall Alford and his colleagues⁵ have just developed an important new facility for measuring nucleon charge exchange reactions in nuclei. As part of the relentless pursuit of possible explicit quark effects in atomic nuclei, worldwide interest has focused recently on the behaviour of the various pieces of the nucleon-nucleus response functions. Some of these pieces, for example the Gamow-Teller (spin and isospin flip) piece appear to be "chiral filers", subject to effects arising from excited nucleons or quark substructure. It is important then to measure (p,n) and (n,p) reactions and to choose cases - specific angles and specific nuclear excited states which enable one to study the energy dependence of the Gamow-Teller and Fermi response functions.

At TRIUMF the MRS proton spectrometer has been used as part of a very newly commissioned facility which measures both (p,n) and (n,p) reaction with reasonably good (~ 1 MeV) resolution. For (p,n) a secondary target placed before the spectrometer measures the energy of knock-on protons produced by the neutrons; for (n,p) a similar primary target produces the knock-on neutron beam. Fig. 3 shows recent spectrums with the system and Fig. 4 a preliminary analysis of the ratio of Gamow-Teller to Fermi strength in ^{14}C as a function of nucleon energy.

This data is a fertile field for theory. In this energy regime the impulse approximation is valid and therefore the effect of the nuclear medium on the nucleon-nucleon force is tractable. The input nucleon-nucleon data exists from TRIUMF's survey². Thus the many-body effects which both enrich and complicate the low energy regime are, in considerable measure, absent here. Theory based on first principles can confront good data.

These are only two vignettes of recent work in the proton hall. A very major nuclear physics program employs the MRS spectrometer directly for nuclear physics.

4. Experiments in the Meson Hall

The production of intense beams of pions and muons - in this order of priority - constituted the driving force behind the development of the meson factories. However, in the initial years of TRIUMF the physics interest has, on the whole, been even greater for the muons than for the pions. The advent of the Standard Model has pushed the muons onto centre stage. Much of what we can and must do with pions still lies ahead.

The muon-pion rivalry remains full of delightful ironies. Because the Standard Model remains silent on an explanation for the mass spectrum of the fundamental fermions, we can still speculate frivolously on how different our world would be if, ceteris paribus, the muon had been made a little heavier so that its mass slightly exceeded that of the pion. On the one hand the charged pions would then last for a significant fraction of a millisecond and we might build storage rings to produce pions galore. Would that make a frontal attack on the confinement issues of QCD significantly simpler? On the other hand we would have scarcely no muons at all, either in cosmic rays or from high energy accelerators. Much would be lost. On the whole we would probably be inclined to leave things as they are. Perhaps even, if we follow Nambu's argument at this conference, the laws of physics have evolved to achieve this happy circumstance. Perhaps the supercolliders will uncover the Higgs particles and the benevolent group symmetry from which this fortunate circumstance about the mass spectrum arises.

The pervasive muon provides such a great deal. I shall only refer to a few recent examples of TRIUMF muon experiments.

One of our simplest muon experiments pertains to a test of quantum electrodynamics (QED) not quantum chromodynamics. Fig. 5 shows the apparatus which Oram et al⁶ used to measure the Lamb Shift in muonium and Fig. 6 shows their result - which was the first such measurement anywhere. The experiment is very simple in principle. Slow positive muons strike a foil. A very small fraction of the muons pick up an electron in traversing the foil to form muonium which emerges. In turn, a small fraction of the emerging muonium is in the $2s$ atomic state. An appropriate RF frequency - which determines the Lamb Shift - quenches the $2s$ state to the $2p$ state. The consequent rapid $2p \rightarrow 1s$ gamma ray is the signal for the quenched muonium.

The present muonium Lamb Shift experiment at the 1% level is not a stringent QED test but it could point toward one. The measurement of the Lamb Shift in atomic hydrogen at the $10^{-3}\%$ level is one of the best QED tests. Further progress here is halted because the nucleus of hydrogen is a proton whose unknown structure enters the analysis at the $10^{-3}\%$ level. In muonium the atom consists of two leptons, point particles not encumbered with any uncertainty arising from hadronic structure. One can hope to push the muonium experiments further.

The next TRIUMF muon experiment is one which was carried out in 1982 and 1983 by Mark Strovink⁷ and a number of colleagues for the Michel spectrum of decaying muons. This experiment remains much the best search in the world for gauge bosons associated with right-handed currents. It much outdoes experiments with high energy colliders in this search for such right-handed bosons of extreme mass. Fig. 7 compares Strovink's result with those of other experiments and shows that within the V-A theory, this experiment provides a lower limit for the W^+ mass of 400 GeV.

It is not surprising that muon-decay is such a sensitive testing ground for right-handed currents. The purely left-handed interaction polarizes the muons at their birth from pions. In the subsequent muon decay, the kinematics simplifies at the high energy end of the positron spectrum for which the two neutrinos emerge opposite to the positron. Here the asymmetry in the positron emission for right-handed currents is opposite to that for left-handed currents. In the Strovink experiment one has a muon polarimeter and a spectrometer to carefully measure the asymmetry of the most energetic positrons.

The purely leptonic decay of muons is still, quite generally, a delightful arena for new physics. Decades ago Michel showed that one only required four model-independent parameters (ρ, η, ξ , and δ) to describe the polarization, angle of emission, and energy spectrum of the decay electrons. Weak interaction models enter into the interpretation of the experimental results for the four Michel parameters. For example, it was the ξ parameter in Strovink's experiment which was particularly sensitive to right-handed currents.

For three of the parameters (η, ξ , and δ) recent TRIUMF experiments^{7,9,10} have provided the most accurate experimental values. For the ρ parameter a 1965 experiment of Bardou et al.⁸ is still the best and agrees with the V-A value of 0.75 to within an error of ± 0.0026 . The η parameter should be zero according to V-A theory and the recent TRIUMF experiment of Crowe et al.⁹ achieves an accuracy of ± 0.1 . This parameter is especially sensitive to the presence of scalar and pseudoscalar couplings. For ξ Strovink et al.⁷ found $|\xi| > 0.9966$ in close agreement with the V-A value of unity. For the δ parameter the same group¹⁰, in another recent TRIUMF experiment found $\delta = 0.748 \pm 0.005$, in agreement with the V-A value of 0.75. This parameter is especially sensitive to the presence of tensor, scalar, and pseudoscalar couplings.

With present techniques it appears that only the measurements of ρ (and possibly δ) could be improved substantially. The high energy parameters (ρ , δ , & $|\xi|$) do not run into the "brick-wall" of internal radiative corrections presently hampering the interpretation of η . There is a great need here for imaginative new ideas about experimental techniques. The theory also needs to be clarified¹¹. Scheck¹² has emphasized the need for a global approach to all of the Michel parameters. One needs to know more precisely what physics would be uncovered by a new generation of experiments and what the relationship

of these measurements is to other muon experiments (g-2, muon lifetime etc.).

My third muon example is TRIUMF's biggest ongoing experiment. It uses a time-projection chamber (TPC) to search for neutrino-less muon conversion.

The rare muon decay modes are flavour-changing and very important in differentiating between various add-ons to the Standard Model. In the muon conversion experiment of Hargroves and Bryman et al.¹³ one searches for events in which a muon, captured by a nucleus, gives its full energy (105 MeV) to an electron. The problem is that the various variants of the Standard Model predict that observable branching ratios for such flavour-changing decay modes are likely to lie significantly below the previous lower limit of $\sim 10^{-10}$. It is a tremendous challenge to design a detector capable of analyzing muon decays one at a time with 10^{13} or more muon stops to search for such rare modes. The TPC, Fig. 8 is such a detector. It has operated at TRIUMF for three years and currently is analyzing more than 10^6 events per second. It has already pushed the limit in the branching ratio to the vicinity of 10^{-11} . Although no events have been seen, the present constraints on theory are important. Technically the TPC has been a tour de force. It is magnificent physics nearly within reach.

Finally I come to a muon industry at TRIUMF in which Tokyo University physicists have played such a leading role. The field of μ SR is burgeoning at both TRIUMF and SIN. The muon is such a versatile probe. Its spin axis is known. Its decay electron, emerging along the spin axis, signals the instantaneous spin direction. It is readily provided in two charge states. The positive muon forms muonium and acts, chemically, like a very light hydrogen isotope. The spinning muon is a good probe for magnetism in condensed matter. At TRIUMF our μ SR program embraces a wide spectrum of studies in solids, liquids, and gases. A full talk on this subject alone would be needed to give you proper impressions of its physics.

Here I restrict my attention to one current example, the observation¹⁴ of a level-crossing resonance which has been investigated for the purpose of studying quantum diffusion of muons in copper. In a level-crossing experiment two energy levels are made degenerate by the application of an external field. In copper this occurs when the μ -Zeeman splitting matches the induced quadrupolar splitting of the muon's nearest neighbour copper atoms. On resonance, the dipolar coupling between the muon and copper atoms gives an enhanced depolarization of the muon spin.

Thus far, the resonance has been observed in single crystals of copper of various orientations over the temperature range from 4.6K to 200K. The longitudinal field relaxation rates which vary from $0.01 \mu\text{s}^{-1}$ off resonance to $0.07 \mu\text{s}^{-1}$ on resonance, are extremely small compared to the muon decay rate of $2.2 \mu\text{s}^{-1}$. Fig. 9 shows the resonance curve measured

for copper with the (100) axis parallel to the incoming muon polarization and external magnetic field at 20K.

Striking changes in the shape of the resonance are observed as a function of temperature which are attributed to effects of muon motion. From a detailed analysis of the data which is in progress, we hope to distinguish quantum diffusion from classical hopping.

As a whole USSR is a new field where interesting physics appears at every turn.

Some experiments on pion's now underway or planned at TRIUMF also look at rare decays and the physics of the Standard Model. Further measurements of the electron decay mode, $\pi^+e^+\nu_e$, are in progress and test the universality of the weak interactions. Measurements of two electron decay modes of neutral pions, $\pi^0e^+e^-$ are planned to be undertaken with an improved TPC because the existing measured branching ratio ($\sim 2 \times 10^{-7}$) is much greater than theory ($\sim 5 \times 10^{-8}$). Also, more measurements of $\pi^+e^+\nu_e$ are nearly completed and provide information on the pion form factor.

Yukawa's pions play an important role as probes for nuclear physics but there are more questions than ever about their role as particles in the nucleus. Physics has always thrived on the re-examination of fundamental old concepts with new ideas. But rarely has the re-examination unfolded so quickly and so dramatically as for the story of nuclear physics and Yukawa's pion.

All of nuclear physics is in a state of constructive turmoil. In the standard model the hadrons are all composites consisting of colour-neutral systems of confined coloured quarks and the strong interaction is quantum chromodynamics, (QCD), the exchange of coloured gluons between quarks. Further, the force is tractable only when the quarks are very close together. It is not easy to obtain the one-pion exchange force as the approximation to QCD for two nucleons separated at distances of several fm or more. However, for such distances the one-pion exchange model is so well rooted in data that there is no question about its correctness even if, in our new picture we view it as a Van der Waals interaction. Instead QCD must pass the test of accommodating itself to this truth. For a nucleus which we always believed to be an aggregate of nucleons with an average separation of about 2 fm, it is not easy to obtain from QCD the picture of individual nucleons in shell model orbits. Still we know from a wealth of data that the shell model must work as an approximation at low energy and again QCD will have to accommodate to this truth.

Beyond these there are few certainties. Does the quark substructure matter? Do the quarks wander? What is the physics of quark confinement? Does the nuclear medium affect the quark momentum distribution? Is the nucleon a bag of confined quarks or a soliton? Does the nucleon contain pions? What is the role of pions in the internucleon medium? At higher energies is it useful to speak about hadronic degrees of

freedom involving excited nucleons and/or explicit mesonic degrees of freedom? There is a great number of such questions and a lot of room for real surprises. The puzzles about the pion are central to all of the issues.

What we embarked upon twenty years ago when the meson factories were developed is still valid. The pion carries unit isospin and interacts strongly. It can participate in both double and single charge exchange and make the nucleus oscillate, rotate, vibrate, pulsate, or whatever. There has been a considerable amount of good nuclear structure physics with pions at each of the meson factories. But one can still look forward to much more.

From initial experiments with pion inelastic and elastic scattering both above and below the Δ resonance, one now knows that low energy pions (~ 50 MeV) have a considerable muon-free path (~ 5 fm) inside the nucleus but the question is how do they propagate in the nuclear medium. All the fundamental questions about quark substructure and confinement come into play. It appears that much of the low energy pion-nucleus data - at the Δ resonance and even much below - can be described by a model in which the pion combines with a nucleon to form a Δ particle. One learns then about the properties of the Δ resonance in the nuclear medium. At TRIUMF a great deal of interesting work has been carried out with very low energy pions.

True pion absorption in the nucleus is not understood although it has already provided some surprises and seems to have the potential for much good physics. In a program which encompasses the pion facilities of all of the meson factories, Ashery and his colleagues are taking the first steps in the exploration of pion absorption. Already one knows that the two-nucleon absorption mode is much less dominant than expected.

Even in the simplest hadronic systems such as $\pi+d$ there is at present considerable controversy. Some careful work at SIN by Gruebier and his colleagues²⁰ for the tensor polarization parameter, t_{20} , of pion-deuteron elastic scattering indicated some startling narrow resonance structure in both energy and angle. If true this data would appear to point to something even more spectacular than a single narrow dibaryon resonance. However, both at LAMPF and at TRIUMF, no such miracle in the data appear to occur. The recent work²¹ of Shtn et al covered precisely the same angles and energies as the SIN experiment with completely different results. There is a great push on now by Smith et al²² at TRIUMF to systematically measure the $\pi+d$ system using a polarized deuteron target being developed for this purpose.

5.

The TRIUMF Applied Program

In the next paper Blaser describes the recent work at SIN for pion therapy. At TRIUMF we have a program of similar scope and also with some initial evidence for the effectiveness of this new tool for cancer treatment. At this conference Sakamoto describes the basis on which

rests the great hope for pion therapy for the treatment of deep-seated tumors. It is only recently, with the achievement of full beam intensity and appropriate secondary channels, that it has been possible for the meson factories to apply pions to the treatment of human patients.

Using large doses (~2000 rads) of pions only, delivered in about 10 fractions to selected patients, our researchers^{2,3} have focussed on abdominal cancers and on certain kinds of brain tumors (gliomas). In these initial preclinical trials one seeks to establish the optimum dose strategy required to achieve local tumor control. There is already some firm evidence that patient survival is significantly enhanced over other treatment forms. This sets the stage for proper clinical trials with several hundred patients in a specific tumor site which could begin in a year or more. The existing experience has not diminished the great hopes for pion therapy.

At TRIUMF, also, we have a thriving business for accelerator-produced isotopes. For this purpose we use our main beam dump (520 MeV protons), a dedicated beam line (2C - see Fig. 1) which yields intense beams of protons of 70-110 MeV energy and also an auxiliary cyclotron with variable energy (15-42 MeV) for 200µA protons beams. This system of beams for isotope production is probably unmatched in the world. The market is growing rapidly for many different accelerator produced isotopes. Some of our isotope production is dedicated to yield positron emitters.

We have built a Positron-Emission Tomograph (PET) which is now in use in the nearby Image Centre of the Acute Care Hospital of the University of British Columbia. Our first PET is a four-ring brain scanner. A whole-body PET is under development at TRIUMF.

These applied programs, and a number of others, are part of the interesting mix of science of a meson factory.

6.

Conclusions

Fifty years ago Yukawa probably never dreamed that his idea about the meson would lead to a worldwide industrial enterprise - the meson factories. In my paper I have attempted to provide a few vignettes to illustrate that meson sciences at TRIUMF are thriving. Our muon program has come into early prominence. Our proton hall program is now beginning to address the new physics which the advent of the Standard Model has brought to the whole field of nuclear physics. The pion program is doing those things which the meson factories were intended to do but also the role of the pion in the nucleus has become much more open to new questions. With new spectrometers and better beam lines, we can envisage that much pion physics lies ahead.

Like any thriving industrial enterprise the meson factories are planning ahead for major expansion. At TRIUMF we have a proposal for a KAON factory which we plan to build, using our present accelerator as an injector. With a system of five new accelerator rings, Figure 10,

we would boost the maximum energy to 30 MeV while maintaining an average beam current of 100µA. Such a facility would produce a hundredfold increase over existing facilities for the production of many secondary particles: kaons, antiprotons, pions, and muons, hyperons, neutrinos, etc. The full science of the KAON factory is outlined in our proposal and would need a separate paper for its description.

Fifty years after the discovery of the meson, the time for the KAON factory has come. Just to illustrate its science importance, I show one experiment, Fig. 11, in which it would bring exciting new physics within reach. The kaon rare decay modes carry the same kind of compelling physics as the muon modes which we are now searching for with our TPC. But they can, at a KAON factory, be measured. (It is always nicer to see something then to establish an upper limit!) There are theoretical limits, based on the mass of the top quark and the lifetime of the B-meson, within which the decay mode for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is expected to be found. Because of the importance of this discovery, TRIUMF is now collaborating on a Brookhaven experiment to search for it. With the increased flux of a KAON factory, one seems very likely to explore its physics. The insight fifty years ago into the physics of the pion has opened doors to work with pions and muons and now promises to tell us so much more with the other members of the meson family. As Nishijima pointed out at this conference, the kaon itself is, next to the hydrogen atom, the richest laboratory which nature has provided. At TRIUMF we plan to open that laboratory for the world.

7.

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FIGURES

Fig. 1 Layout of the TRIUMF Facility (1984).

Fig. 2 Experimental layout of a test of charge symmetry in n-p elastic scattering at 480 MeV.

Fig. 3 a) (n,p) spectrum obtained with knock-on neutrons from 300 MeV incident protons on a ${}^6\text{Li}$ neutron production target. The resolution of 1 MeV is indicated.
b) (p,n) spectrum from a ${}^{14}\text{C}$ target.

Fig. 4 The ratio of the Gamow-Teller to Fermi strength as a function of the proton energy. TRIUMF can map out the interval between 180 and 520 MeV.

Fig. 5 A schematic of the apparatus for the muonium Lamb-shift experiment showing a good event in which a Lyman α photon is detected in the microchannel plate (MCP1) from de-excitation of $\mu^+e^-(2s)$ in the quench region.

Fig. 6 The intensity of the muonium 2P-1S signal is plotted (triangles) for the measured rf frequencies and powers. The circles, representing the background intensities give an independent test of the normalization. The smooth curve is a fit.

Fig. 7 Experimental 90% confidence limits on the W_{LP} mass-squared ratio and mixing angle describing possible right-handed charged currents. The bold curve is the new TRIUMF result of Strovink et al (Ref. 7).

Fig. 8 A perspective view of the TPC. The TPC has 12 sectors with 12 anode wires per sector separated radially by 2.54 cm. The innermost wire is at a radius of 19 cm. The maximum drift length to the central high voltage plane is 34 cm. The numbered elements are: (1) the magnet iron, (2) the coil, (3a) & (3b) trigger scintillators, (4) outer trigger proportional counters, (5) end-cap support frame, (6) central electric field cage wires, (7) central high voltage plane, (8) outer electric field cage wires, (9) inner trigger scintillators, (10) inner trigger cylindrical proportional wire chamber, and (11) end-cap proportional wire modules for track detection.

Fig. 9 $\mu^+\text{SR}$ level crossing resonance with Cu nuclear quadrupole splittings in a Cu crystal at 20°K with $\langle 111 \rangle$ axis parallel to the longitudinal applied field.

Fig. 10 Proposed layout of the accelerators for the proposed TRIUMF KAON factory. The 30 GeV main ring encircles the existing TRIUMF meson factory.

Fig. 11 History of the branching ratio for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay showing how, with a KAON factory, one encompasses the region for which the decay is predicted to occur.

BEAMLINES AND EXPERIMENTAL FACILITIES

Fig. 2.

Fig. 5

Fig. 3

Fig. 6

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Fig. 7

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Fig. 10

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Fig. 11