Contents

1 DESCRIPTION OF THE PROPOSED CENTRE

- **This Centre will build a world-leading research team in Adelaide, with the aim of making major advances in our understanding of the subatomic structure of matter.**
- Progress in the field has been hampered by poor communication between the highly specialized groups working in various sub-fields. We believe that by carefully coordinating the most promising approaches within the one centre we are much more likely to produce major advances than a number of isolated individuals or small groups.
- In order to aggressively pursue the **coherent research program** necessary to make **major advances** in this field it is essential to have the level of funding and the length of commitment which is **only available through the Special Research Centre program**.
- In conducting a research program of the highest quality we will attract the very **best researchers in the field from around the world** for significant periods of time.
- Through a vigorous program of topical workshops and postgraduate seminars, as well as a Visiting Fellow scheme aimed at Australian scientists, **the entire Australian community of theoretical physicists interested in strong interaction physics will be involved in the research program of the Centre.** As well as strengthening the research program of the Centre, their own productivity and enthusiasm will be significantly enhanced.
- The research in theoretical subatomic physics at the Centre will **benefit many other areas of theoretical and experimental physics and mathematics**. All physicists and mathematicians who could benefit from (or assist) the research activities of the Centre (especially the workshops) will be encouraged to participate. This will be of particular importance to the experimental groups working in high energy and nuclear physics.
- **Postgraduates and postdoctoral fellows** working within the stimulating atmosphere of the Centre will be collaborating with the very best researchers in the field on a daily basis. Those in other institutions will benefit from the topical workshops and wherever possible we shall arrange for introductory courses preceding the workshops.
- The Centre will provide a **national focus for postgraduate (and postdoctoral) education in theoretical physics**. We shall actively seek funds to support the production of a range of coursework materials for use across Australia, including lecture materials (published in conventional form or distributed via the World Wide Web), tutorials, and videos.
- It is vital that a Centre such as this, with a flow of the world experts in subatomic physics, strive to **inform the public** of the developments in the field. Thus we aim to support a program of public lectures and media appearances aimed at the general public.
- Wherever the expertise of our visitors may be of use to Government research organizations or industry we will strive to build appropriate links. In the longer term such activities may be expected to open opportunities to secure funding for our scientific activities. Developing and maintaining such alternate sources of long-term funding will be an important objective of the Centre.

1.1 Scientific Framework

Hadronic (i.e., strongly interacting) matter makes up almost the entire mass of the tangible universe, from the protons and neutrons in nuclei inside atoms and molecules to neutron stars. Unravelling the rich and complex structure of the hadrons and their interactions is one of the remaining great challenges in physics. The marvellous organizing principle for almost all of our understanding of modern physics is referred to as the Standard Model. This brings together in one elegant framework three of the four fundamental interactions in physics: the electromagnetic, weak (responsible for radioactive decay), and the strong interaction (responsible for hadronic structure and interactions).

In spite of the impressive achievements of the Standard Model, the component of it responsible for the strong interactions, referred to as Quantum Chromodynamics (QCD), has so far only been solved in the very high energy (or perturbative) regime. Hadronic matter, on the other hand, is almost always to be found at lower energies (i.e., in the nonperturbative regime). Hence, the central goal of this proposal is to resolve this situation by establishing a robust and meaningful connection between QCD and the observed hadronic world.

The fundamental constituents of the QCD description of hadronic matter are referred to as quarks (analogues of electrons) and gluons (analogs of photons, but self-interacting). Assuming that QCD is the correct theory for the strong interactions, we will use it to understand the observed structure of hadrons and hadronic matter and to predict new important features. Conversely, when pushed to its limits, QCD may eventually fail to predict the observed hadronic world. This possibility would constitute an extremely interesting outcome and would require major modifications to the Standard Model.

This is an opportune time to undertake studies of this type, since, in addition to ongoing work at established laboratories like CERN, SLAC, Fermilab, Bates, Bonn and Mainz, new experimental facilities which will offer different insights are coming on-line now (e.g., at HERA, COSY, CEBAF, and RHIC) or are in the planning stage (e.g. ELFE and LISS). As we shall outline in Sec.2.1 (on current activities) we have played and continue to play a significant role in the design and interpretation of experiments at these laboratories. This work will provide vital clues in our quest to understand the structure of matter at its deepest level.

1.2 Benefits

• **Culture:** We shall create an international research centre of excellence in the investigation of hadron structure. This comes under general heading of the advancement of knowledge which is in itself a valuable goal. Furthermore, to maintain our membership in the international scientific community we must continue to make outstanding contributions in some areas of basic science – especially those where we are already strong.

• **International Links and Postgraduate Training:** The Centre will be extremely cost efficient in bringing the world's best researchers in the field to Australia. For many of these our University salary system could not match even half of their regular salaries, but they will visit an active research centre for travel and living costs alone if the science is good enough - and it will be. While here they will contribute to postgraduate and postdoctoral education and stimulate the Australian scientists with whom they collaborate.

• **Graduates of high quality:** The Centre will produce graduates of the highest quality by international standards. Apart from developing their technical skills in physics, mathematics and computing they will learn to work in strong, often multi-national research teams.

• **Postgraduate Training:** The Centre will help to raise the standards of postgraduate teaching in related areas of theoretical and experimental physics across the country. In particular, it will assist in the coordination and development of postgraduate courses for students throughout Australia. Some of these may be suitable for marketing overseas.

• **Education:** Subatomic physics has enormous power to stimulate the minds of young people and to draw them into tertiary study in science and mathematics – regardless of what they eventually choose as a career. Because of this we hope to play a part in redressing the recent decrease in the number of able students choosing to study these areas.

• **Public Awareness:** Through an emphasis on public lectures and talks at service clubs and business groups we aim to raise the profile and public awareness of science.

• **International Exchanges:** We shall continue to extend existing research collaboration and formal agreements by building new programs with major research centres in Asia, Europe and North and South America.

• **International Links:** We aim to keep the public, government and other academics abreast of the latest developments in high cost experimental areas Australia cannot afford – as well as with the associated technology. Through the connection to major laboratories like CERN and HERA this will include access to recent developments in Information Technology. (For example, the World Wide Web was developed at CERN as a tool to permit large scale sharing of data across international collaborations.)

• **Interaction with Industry and Other Research Organizations:** We will stimulate interaction with government research laboratories (such as ANSTO, CSIRO and DSTO) and industry wherever possible.

2 RESEARCH AND TRAINING PROGRAMS

2.1 Current

The Adelaide region is rich in talent in theoretical physics. At Flinders University Drs. R. Cahill, I.R. Afnan and B. Blankleider are well known internationally for their work in few body problems in hadronic systems. As well as the principal investigators, the University of Adelaide has Dr. R. Crewther (an expert in gauge field theory) and Dr. B. Pearce (a QEII Fellow expert in hadronic physics), as well as a mathematical physics group which includes Prof. P.C.W. Davies and Drs. J. McCarthy, P. Szekeres and D. Wiltshire. The mathematical physicists are expert in general relativity and quantum field theory and we share a weekly seminar and the teaching of third year, honours and postgraduate courses in theoretical physics.

The principal investigators already have an outstanding program of Visiting Research Fellows. Typically there are up to a dozen senior visitors who come each year to work in the University of Adelaide theory group for periods from a month to a year. These visitors interact with the honours (currently three) and postgraduate students (currently eleven) as well as the research associates and senior staff. They also visit other theorists around the country and are encouraged to participate in topical workshops and schools to the benefit of all. Most importantly, however, these visitors participate in research projects that regularly lead to joint publication in international, refereed journals.

The impact of such Visiting Fellows cannot be overstated. They fulfil a role which in some sense can be viewed as the ultimate in quality control. Through them our students and research associates, who cannot travel often to offer their work for review at international conferences, are able to see that their work is internationally competitive. We firmly believe that this emphasis on international competitiveness is one of the key reasons that two of the first three **Gold Bragg Medals** (awarded by the Australian Institute of Physics for the best Ph.D. thesis in Australia in the year of graduation) have gone to our students (Dr. S.D. Bass 1992 and Dr. W. Melnitchouk 1994).

In order to further strengthen these links we have entered into a number of **formal exchange agreements** with key centres overseas: the Chinese Academy of Science in **Beijing**, the Research Centre for Nuclear Physics in **Osaka**, the Institute for Theoretical Nuclear Physics in **Bonn** and the KFA in **Juelich**. We are currently negotiating further agreements with key centres in hadron physics in the United States, France, and Russia. Copies of these agreements (signed on behalf of the University of Adelaide by either the Vice-Chancellor or the Dean of Science) can be provided on request. The willingness of these overseas centres to enter into agreements with us is one indication of the international standing our group already has.

Although the report on current research activity has more details, it is worth recording here that, in addition to the links with centres of theoretical physics, we are actively involved in the design and analysis of experiments planned or being performed at most of the world's major laboratories for nuclear and particle physics.

Following the preparation of a **Strategic Plan for Physics in Australia** three years ago, which emphasised the need for a National Institute for Theoretical Physics, the National Committee for Physics organised a national competition to determine the site. On the advice of the Directors of comparable centres overseas, a bid involving several other universities (Flinders, UNSW and the ANU) with Adelaide as the main site and Prof. A.W. Thomas as Director was chosen. This bid received (and continues to receive) tremendous support (both moral and financial) from the Government of South Australia ($130k), DSTO ($30k p.a. for four years), Digital Equipment Corporation (in kind support) and Adelaide and Flinders Universities (approximately $200k in 1995 and 1996).

Since being chosen as the lead site for the National Institute (in April 1995) we have fitted out 350m^2 of space on the 4th floor of 10 Pulteney Street. This space includes seven dedicated DEC-α workstations (networked with the Department of Physics and Mathematical Physics), office space, a seminar room and reception area. Furthermore, we have conducted five topical workshops involving more than 200 theoretical and experimental physicists as well as postgraduate students and key overseas speakers.

In the area directly relevant to this Centre, our Joint Australia-Japan workshop on "Quarks, Hadrons and Nuclei" last November was a major success. It brought together 25 key Japanese theorists and a slightly larger number of Australian participants to work together for a period of two weeks on front-line problems in the structure of hadronic matter. This will certainly lead to continued collaboration. For example, Prof. Tatsumi (Kyoto University) has already asked to return for about 6 weeks in March-April 1996 to continue the joint investigation of kaon condensation in dense nuclear matter which began at the workshop.

In conclusion, theoretical physics in Adelaide is a major national resource with valuable links across the world. We are exceptionally well placed to build an outstanding international centre of excellence in the Subatomic Structure of Matter.

2.1.1 Current Research Activities

We have considerable experience in theoretical calculations of hadron structure. With Prof. W. Weise (Technical University of Munich), Professor Thomas is currently preparing a postgraduate text on the Structure of the Nucleon. This is intended to summarise the state of the art in the experimental and theoretical study of nucleon structure and to define directions for further research. It should be completed by mid-1997. Perhaps our best known work in the field is the cloudy bag model (CBM) developed in the 1980's by G.A. Miller, S. Théberge, AWT and many others. This work has received several thousand citations and helped to define many of the crucial features of (especially) nucleon structure that any sophisticated treatment should include. The CBM emphasised the importance of chiral symmetry in baryon spectroscopy with a significant fraction of the N-Δ mass splitting coming from pion self-energies. It led to a convergent expansion for the charge form-factor of the neutron (G_{En}) and, in particular, gave a natural explanation of the negative tail of the neutron charge density.

Amongst the recent highlights of our work on hadron structure, involving the solution of non-perturbative gauge field theory and relativistic bound states, we mention the successful formulation and solution of the Bethe-Salpeter equation for scalar theories in Minkowski space without any of the usual three-dimensional reductions. Another significant achievement was the successful inclusion of a numerically implemented renormalization scheme for Dyson-Schwinger equation studies. This and related work was recently the subject of an extensive review [C.D. Roberts and AGW, Chapter 7 in *Progress in Particle and Nuclear Physics, Vol. 33*, A. Faessler (Ed.), pp. 477-575].

The direct calculation of the structure of hadronic matter in non-perturbative QCD is an extremely difficult problem. It is vital that every available piece of experimental information be used to test the state of our theoretical understanding and to suggest new theoretical approaches. Here too we continue to play an important role internationally. For example, we pioneered the use of deep-inelastic scattering (DIS) to constrain models of the structure of the nucleon. In 1983 we proposed that the pion-nucleon form factor, which plays an important role in many aspects of nuclear physics especially the NN force, could be constrained by the excess of non-strange over strange quarks in the nucleon sea. We also predicted an excess of $\bar{d}$ over $\bar{u}$ quarks in the sea of the nucleon [AWT, Phys.Lett. B126,97 (1983)], which was observed by the New Muon Collaboration (NMC) at CERN almost 10 years later. The role of the pion cloud of the nucleon in inclusive and semi-inclusive DIS is the subject of an enormous amount of current research. Experiments to clarify it are continuing at CERN (Geneva) and are being planned at many other laboratories including HERA (in Germany) and CEBAF (in the USA). We are in contact with the experimentalists involved, as well as the local theoretical groups, and will play a significant role in the analysis of these experiments.

Just a few years ago our understanding of nucleon structure within QCD was severely challenged by the European Muon Collaboration (EMC) at CERN, with its discovery that the Ellis-Jaffe sum-rule is badly violated [J.Ashman *et al.*(EMC), Nucl.Phys. B328,1(1989)]. The naive, parton model interpretation of this observation is that the valence quarks carry almost none of the spin of the proton - in apparent contradiction of the success of the usual quark model. This became known as the "proton spin crisis". It was soon realized that the U(1) axial anomaly had the potential to resolve this crisis, although there was a difficulty in relating the appearance of this correction in the QCD improved parton model with the usual operator product expansion (OPE) treatment. We contributed to the theoretical understanding of the EMC result from the very beginning, examining the corrections associated with the pion cloud of the nucleon [A.W.Schreiber and AWT, Phys.Lett. B215,141(1988)] as well as gluon exchange

[F.Myhrer and AWT, Phys.Rev. D38,1633(1988)]. Most recently we have examined the role of strange and charm quarks in the actual experiments performed – rather than the Bjorken limit, which is rather far away. The inclusion of charm reduces the amount of polarised glue needed to understand the data - although it is still uncomfortably large [F.Steffens and AWT, Phys.Rev. D53,1191(1996)].

It is more than a decade since the EMC discovered that the deep-inelastic structure functions of atomic nuclei are not the same as those of a free nucleon. We have just completed a major review of this subject at the invitation of the editors of Annual Review of Particle and Nuclear Science [D.F.Geesaman, K.Saito and AWT, Ann.Rev.Part.Nucl.Sci. 45,337-390 (1995)]. While there is, as yet, no complete understanding of the data, an enormous amount has been learnt about deep-elastic scattering from nuclear systems. To cite just a single example, we mention the application of our recent studies of the off-shell behaviour of the structure function of the nucleon to the structure function of the deuteron [W. Melnitchouk *et al.*, Phys.Lett. B335,11 (1994)]]. This led to a recent re-analysis of the large-x behaviour of the structure function of the neutron (or equivalently the d/u ratio). In the absence of free neutron targets this must be extracted from deuteron data by subtracting the proton data after correcting for binding, Fermi-motion and off-shell effects. Most modern text books ignore the ambiguity in this process and quote the result $F_{2p}/F_{2n} \to 1/4$ as $x \to 1$. Although this agrees with one set of theoretical predictions it disagrees with those derived from perturbative QCD [G.R.Farrar and D.R.Jackson, Phys.Rev.Lett. 35,1416 (1975)]. Our re-analysis of very accurate SLAC data in the large-x region shows that the perturbative QCD result seems to be correct and $F_{2p}/F_{2n} \to 3/7$ rather than 1/4 [W. Melnitchouk and AWT, nucl-th/9602038, to appear: Phys.Lett. B(1996)].

As a probe of the applicability (or otherwise) of perturbative QCD to exclusive processes, we have studied the large momentum transfer behaviour of the pion electromagnetic form factor in the spacelike region in terms of a generalized perturbative integral representation for the covariant, gauge-invariant $q\bar{q}$ pion wave function – in Minkowski space-time [A. Szczepaniak and AGW, Phys.Lett. B302,87 (1993)]. We found that at intermediate values of Q^2 (i.e., $Q^2 \simeq 5\text{GeV}^2$) the nonperturbative contribution has a magnitude comparable with the purely perturbative one – suggesting that perturbative QCD cannot be expected to be reliable for this form factor at intermediate Q^2. This study was subsequently extended [A. Szczepaniak and AGW, Int.J.Mod.Phys. A11,655 (1996)] to include both the pion electromagnetic and $\gamma^* + \pi^0 \to \gamma$ transition form factors at intermediate momentum transfer.

One of the most fundamental questions in nuclear physics is the role of the internal structure of the nucleon in determining the properties of nuclear matter. At high density (and temperature) one expects a transition to a new phase of hadronic matter, the quark-gluon plasma. Major experimental facilities in Europe and the USA are designed to investigate the properties of high density matter and, in particular, to search for this phase transition. Over the past eight years we have made important progress in the theoretical treatment of nuclear structure including the internal structure of the nucleon. The quark-meson coupling model (QMC) may be viewed as a generalization of the extremely successful theoretical treatment of hadronic matter, known as quantum hadrodynamics (QHD), to include the internal structure of the nucleon. As in QHD the interaction between nucleons is mediated by scalar and vector mesons but these couple to confined quarks rather than piont-like nucleons. Nuclear saturation is then primarily a consequence of the accommodation of the quark wave functions to the mean scalar field generated by the other nucleons.

A major recent advance in our work with the QMC model was the success in generalizing it to finite nuclei, where the scalar and vector fields vary across the finite size of the nucleon

[P.A.M. Guichon et al., nucl-th/9509034,to appear: Nucl.Phys. A (1996)]. The phenomenological consequences are currently being thoroughly investigated but the model produces excellent charge densities for nuclei from oxygen to lead. In addition, it suggests a very natural explanation of the absence of a significant spin-orbit force in Λ-hypernuclei. Other consequences for systems involving strangeness are under investigation.

Relativistic heavy ion collisions have already produced hadronic matter at many times regular nuclear matter density. While there is so far no suggestion of quark-gluon plasma formation (and no consensus on a clear signal) the data on lepton pair production has been interpreted in terms of a substantial decrease in the mass of the ρ meson [G.Q.Li *et al.*, Phys.Rev.Lett. 75,4007 (1995)]. A critical ingredient in that analysis was our suggestion [K.Saito and AWT, Phys.Rev. C51,2757 (1995)] that the vector mesons themselves can also act as source of scalar field, thus lowering the hadron masses in dense matter more than one might otherwise expect.

2.1.2 Summary

In the space allowed we have been able to do little more than provide a taste of some of the research programs underway. We stress that:

- we already have an extremely active and productive group, well integrated into the international community working on the structure of hadronic matter.
- with this strong track record, proven productivity and research links we are in a position to make outstanding use of the resources that the Special Research Centre will provide.

2.2 Planned

The primary purpose of this proposal is to enable the Principal Investigators to take a strong internationally recognised record of research and develop it into a major international Centre conducting research into the structure of hadrons and hadronic matter. The research program will be carried out under the direction of Prof. Thomas, with the Centre providing an ideal environment for the related activities. Thus, while the visiting researchers (including the Associate Investigators) will provide a valuable source of knowledge and new ideas and will also take research ideas (and other benefits of involvement) back to their home institutions, Adelaide will be the focus for their participation in the research program of the Centre.

In order to build the broadly based, coherent research program, required to make major advances in the field, it is essential to have the level of funding and the length of commitment offered by the Special Research Centre program. The activities of the Centre fall into two broad categories. Firstly, there are the long-term research goals. Each of these has associated with it a number of shorter-term, strategic aims which will evolve with time – as progress is made towards the long-term goal. Secondly, there are the every day activities of the Centre, such as the visitor programs, topical workshops, postgraduate training, research seminars and so on. We begin with an outline of the long-term goals and a selection of the strategic investigations to be pursued first. Then we briefly summarise the mode of operation of the Centre.

2.2.1 Planned Research Activities

The long-term research goals of the Centre are to:

• develop calculational tools for the solution of non-perturbative quantum field theory in order to determine the predictions of QCD for the structure of individual hadrons and hadronic matter.

• develop an understanding of the nature of confinement, its relationship to dynamical chiral symmetry breaking and critical coupling.

• improve our understanding of the structure of hadrons at a fundamental level by studying the essential symmetries and properties of the underlying quantum field theory and incorporating them into suitably sophisticated models.

• examine the changes in hadron structure in various nuclear environments.

• answer the crucial question:

"How important are quark and gluon degrees of freedom for describing nuclear physics?"

• investigate the properties of hadronic matter under extremes of density and temperature, including phase transitions.

• devise, plan and analyse experiments at major laboratories around the world which will reveal new features of the structure of free hadrons and of hadronic matter, or test predictions of existing models.

• use the results of experimental investigation to continuously refine the models and improve the methods of calculation of hadronic properties.

Models of hadron structure provide a concise, intuitive (as well as quantitative) summary of the physics which is essential to understand a range of physical phenomena. Those based on QCD need to incorporate key physical concepts, such as confinement and asymptotic freedom as well as its symmetries (notably chiral symmetry). They should also respect various known limits – e.g., large–N_c [T.D. Cohen, hep-ph/9512275]. Good models play a vital role in stimulating experimental tests and in analysing data. Through refinement in the light of experiment, these models may also stimulate new ideas and improvements in the direct numerical solution of QCD. In addition, we note that a nucleon model is an essential starting point in the development of a consistent, microscopic theory of the nuclear many-body problem, including finite nuclei, dense nuclear matter and the eventual transition to a quark-gluon plasma.

Current experimental programs are exploring the structure of matter in regions of energy and momentum transfer greater than ever before. In order to interpret such data it is vital to build covariant models of hadron structure which respect chiral symmetry and other known properties of QCD. The Dyson-Schwinger formulation of QCD has an important role to play in developing such models [C.D. Roberts and AGW, Prog.Part.Nucl.Phys., 33,477 (1995)]. One of the outstanding challenges presented by QCD is the nature of confinement for light quarks. It will be important to explore the possible existence of a critical coupling strength in the infra-red region [V. Gribov, Phys.Lett. B194,243 (1987)] and the connection between this and the ultraviolet behaviour of the U(1) sector of the standard model [S.D. Bass and AWT, Mod.Phys.Lett. A11,339 (1996)]. The Dyson-Schwinger approach offers one promising line of attack on this problem [D.C. Curtis and M.R. Pennington, Phys.Rev., D48,4933 (1993)].

Further studies of the non-perturbative quark propagator, gluon propagator, and dynamical chiral symmetry breaking (DCSB) will be undertaken within the Dyson-Schwinger approach. The principal aim of these investigations is to construct confining models which are covariant, obey gauge and chiral symmetry requirements, and reproduce perturbative QCD behaviour in the asymptotically free regime. These studies of DCSB require solving the Dyson-Schwinger equation (DSE) for the quark self-energy in the form of a pair of coupled integral equations. This can be performed on a variety of platforms (e.g., CRAY Y-MP, CM-5, and various powerful RISC based workstations). We are exceptionally well-positioned to explore the relationship between the DSE approach, lattice gauge theory, and sophisticated models of hadrons. Significant advances are expected from a successful cross-fertilization of these approaches.

While the necessity to truncate the Dyson-Schwinger equations at some point will always be unavoidable, advances in lattice gauge theory (LGT) studies of QCD are beginning to provide valuable new information. These two approaches to studying nonperturbative field theories are complementary, each able to provide some component the other lacks. For example, there have been very recent studies of QCD with covariant gauge fixing on the lattice, where the quark propagator [J.I. Skullerad et al., UKQCD collaboration, hep-lat/9412014] and the gluon propagator [P. Marenzoni et al., Nucl. Phys. B 455, 339–356, (1995)] have been extracted numerically in Landau gauge. Because of the presence of Gribov copies in nonabelian gauge theories some caution will be needed in order to decide whether LGT Landau gauge fixing and DSE Landau gauge fixing are truly equivalent.

The direct, numerical solution of QCD will be a major component of the research program of the Centre. Lattice QCD has already provided extremely important results on hadron structure and we will support a strong program which extends the existing collaboration between Prof. B.H.J. McKellar and Dr. T. Kieu at the University of Melbourne and Dr. Williams. (Other important work, which is closely related, is the lattice Hamiltonian work of Dr. C. Hamer at UNSW.) The electroweak form factors of hadrons offer powerful constraints on calculations of hadronic structure and lattice QCD enables first-principles theoretical calculations of them [e.g., D.B. Leinweber *et al.*, Phys.Rev. D43,1659 (1991); W. Wilcox et al., *ibid*,1109 (1992)]. Attempting to improve the techniques for extracting these form factors from calculations of quark configurations will be a significant component of this work. Through the comparison with various models of hadron structure, lattice calculations may be used to provide guidance in the construction of more realistic models.

The international nature of the research and the large collaborations in this area are an inevitable consequence of the need for sometimes enormous amounts of CPU time on the fastest supercomputers in order to generate the necessary field configurations. For example, the form factor studies described above will be carried out in collaboration with the group led by Prof. K.-F. Liu at the University of Kentucky – a collaboration which has already been initiated, with exchange visits in 1993 and 1995. We also plan to build on the existing close ties with the UK effort (the Edinburgh group in the UKQCD collaboration) and lattice gauge theorists at the Supercomputer Computations Research Institute in Florida (A. Kennedy *et al.*). One should not underestimate the need for clever ideas to speed computation in this field and a close collaboration between model building, experimental analysis and lattice theorists is one of the most promising sources of such ideas.

The role of sea quarks [e.g., S.-J. Dong *et al.*, Nucl.Phys. B (Proc. Suppl.) 30,487 (1993)] will be another of the key questions examined and will require access to significant computer resources. This is closely related to chiral symmetry breaking and the role of the pion, which needs to be explored further on the lattice. Another extremely challenging problem, needing more work urgently, is the "proton spin crisis". As explained in Sec. 2.1.1, this involves the axial anomaly, which in turn involves quark loops. Sources of systematic error in the state-of-the-art LGT calculations will be investigated, as will the means to improve them.

A rather different, but promising approach to the non-perturbative solution of QCD is based on Light-Cone Field Theory(LCFT) [e.g., S.J. Brodsky and D.G. Robertson, SLAC-PUB-95-

7056]. The light-cone approach has recently been suggested as the most likely way to rigorously derive a constituent quark model from QCD [K.G. Wilson *et al.*, Phys. Rev., D49,6720 (1994)] – although the approach still faces a formidable array of technical problems. We are especially interested in exploring the vacuum structure in LCFT and, in particular, how dynamical chiral symmetry breaking is manifest. We also note that Dr. L. Hollenberg (Melbourne) has recently presented some interesting suggestions which combine lattice techniques with LCFT and which may provide a useful way forward [L. Hollenberg and N.S. Witte, Phys.Rev., D50,3382 (1994)].

Non-perturbative methods such as LGT and QCD sum-rules have also been applied to the calculation of the low moments of certain parton distributions. In Sec. 2.1 we remarked on the potential importance of deep-inelastic scattering in helping to extract key features of hadron structure. It will be very important to improve these and other non-perturbative methods of calculating parton distributions. We recently completed a calculation of the valence quark distribution for a convariant, scalar di-quark spectator in which the bound-state vertex function was obtained by solving the corresponding Bethe-Salpeter equation in ladder approximation. Extensions of this work will involve the addition of pseudo-vector, di-quark spectators and the use of the perturbation theory integral representation [e.g. K. Kusaka and AGW, Phys. Rev. D51, 7026 (1995)] to yield a solution for arbitrary four-momenta in Minkowski space-time.

It will be very important to explore the connections between the very successful phenomenology of Glück, Reya, Vogt and collaborators (GRV) [M. Glück *et al.*, Z.Phys., C67,433 (1995)] and our own work on the parton distributions for (so far) simple quark models. There appear to be remarkable similarities between their low momentum scale distributions and those predicted by (e.g.) the cloudy bag model. Since the work of GRV has proven highly successful in predicting the behaviour of the parton distributions observed at HERA (at small-x and high Q^2) this comparison could be extremely valuable. In particular, we expect the small-x behaviour to contain important information on the mechanism for confinement and the nature of the QCD vacuum [e.g., J.D. Bjorken, SLAC-PUB-7096 (1996)]. We shall also continue to work closely with the groups at CERN, Fermilab, CEBAF and HERA on the design and analysis of experiments probing vital aspects of hadron structure such as: charge-symmetry violation in the sea of the nucleon and in the valence quark distributions of the pion and the nucleon [e.g., G. Garvey *et al.*, Phys.Lett. B340,115 (1994)]; flavour symmetry violation in the sea and the spin and flavour distributions at large-x. As already explained in Sec. 2.1.1, the latter should provide important information on the role of perturbative QCD.

We have explained at some length the power of deep-inelastic scattering in resolving the quark structure of matter. In parallel with the development of an increasingly sophisticated quark-level description of nuclear structure we will be able to make a consistent, microscopic calculation of nuclear structure functions. Only in this way can we hope to extract the maximum possible information from the data on the nuclear EMC effect. This data is extremely valuable as it gives us our most direct view of the energy and momentum distribution of quarks in nuclear systems.

We have an ongoing program related to experiments to be performed at the most modern electron accelerator laboratory in the United States, the Continuous Electron Beam Accelerator Facility (CEBAF), which uses a high intensity, 4 GeV electron beam to probe hadronic and nuclear structure. For example, we continue to be involved in calculations of ϕ-meson production, which is an attempt to measure the strangeness content of the nucleon [E.M.Henley, G.Krein, S.J. Pollock, and AGW, Phys.Lett. B269,31 (1991); G. Krein, E.M. Henley, and AGW, Phys.Lett. B281,178 (1992)]. These calculations have already directly led to an approved experiment to be performed at CEBAF [CLAS collaboration (W.K. Brooks,*et al.*),

CEBAF-PROPOSAL-93-022(1993)].

As a second example, we mention our recent work on virtual Compton scattering [P.A.M. Guichon *et al.*, Nucl.Phys. A591,606 (1996)]. This paper established the framework for analysing a completely new series of experiments on the structure of the nucleon in terms of 10 "Generalized Polarizabilities". The feasibility of such measurements has just been demonstrated at the Mainz microtron, where a Saclay group has made the first measurements. However, the enormous kinematic range at CEBAF offers a tremendous opportunity for new insights into hadron structure [C. Audit *et al.*, CEBAF proposal PR-93-050 (1993)]. We shall continue to be involved in the development and analysis of these experiments and, through the Centre, in feeding this information back into the models and calculations of hadron structure.

When it comes to the investigation of the importance of quarks and gluons in complex nuclei and nuclear matter, the possibility of a direct solution of QCD is small. In this case one will need to work with models of hadron structure. Our starting point for these developments will be the QMC model described in Sec. 2.1. We shall replace the simple MIT bag model with much more sophisticated nucleon models. By building in chiral symmetry we hope to replace the exchange of an effective scalar meson by microscopic two-pion-exchange. The first workshop at the new Centre, in February and March 1997, will be built around the expertise in the structure of dense nuclear matter of Prof. G.E. Brown (Stony Brook) who will be in Adelaide in that period. It will explore the changes in hadron properties in dense matter in various approaches including the QCD sum rules, the QMC model and so on.

One way of viewing the success of the QMC model is that it naturally builds two *and* three-body forces into the description of nuclear matter. (The change in nucleon structure caused by the mean scalar field affects the interaction with other nucleons.) It will be very useful to build a consistent set of two and three-body forces within the conventional approach to the nuclear force - e.g. the Bonn potential - in order that we can compare results with the QMC model. A collaborative proposal to do this (involving Dr. Afnan at Flinders, Drs. Williams and Pearce and Prof. Thomas at Adelaide and Drs. Haidenbauer and Holinde at the KFA Juelich) has been funded by the DFG in Germany at the level of approximately DM30k per annum for 1996 and 1997. It will also be extremely valuable to have the involvement, through the Centre, of Prof. McKellar who was one of the pioneers in the calculation of the three-nucleon force.

There is enormous interest in the possibility of a chiral phase transition at some critical density, ρ_c, perhaps as low as 2-3 times nuclear matter density. Our work in the QMC model already shows that $< \bar{q}q >$ vanishes in this range, but the nature of nuclear matter at this point seems to involve lumps of positive and negative quark condensate, not a simple chiral phase. Clearly this needs urgent investigation because relativistic heavy ion collisions are already producing matter with densities in this range.

Another fascinating possibility, with dramatic consequences for processes such as the cooling of pulsars, is that dense hadronic matter may have a kaon condensed phase. This was the subject of considerable discussion at our joint Japan-Australia workshop on "Quarks, Hadrons and Nuclei", with the Kyoto group reporting their work on the subject. Professor Tatsumi (Kyoto University) will visit Adelaide in April this year to continue our investigation of the effect of nucleon internal structure on these predictions. The issue of kaon condensation is also closely related to the possible existence of strange matter. In spite of speculation for many years that very large lumps of strange hadronic matter could be stable there has been no experimental confirmation. This work has important consequences in nuclear astrophysics and in this area we intend to collaborate with members of the SRC for Theoretical Astrophysics (in Sydney), as well as members of the theoretical nuclear physics community.

2.2.2 Operation of the Centre

As Director, Professor Thomas will be totally committed to the research programs of the Centre for its nine year duration and beyond. (The University will require no teaching or administrative duties other than those associated with the Centre.) He will maintain daily contact with staff, students and visitors. As Deputy Director, Dr. Williams will commit at least half of his time to the Centre and will share this supervisory role – taking responsibility for the overall operation during any absence of the Director. In some specialised areas, the Principal Investigators will be assisted by Senior Research Associates recruited because of their particular expertise. Associate Investigators outside of Adelaide will be encouraged to visit the Centre regularly and to use the internet as a major tool for communication. The appointment of a full-time computing officer will be vital to provide technical support for the computer-based, research activities, assistance for visiting researchers and advice on computer-assisted teaching initiatives and software and hardware upgrades – as well as looking after the day to day operation of the system. It is intended that on average one position will be devoted to Visiting Research Fellows (most likely but not exclusively Associate Investigators) from within Australia. Such visits would typically last between one month and a full year and would serve to get collaborative research projects to the stage where they can be continued at the visitor's home institution.

We have stressed many times the vital role that leading experts from overseas, attracted by the international quality of the work at the Centre, can play. Their presence will stimulate staff, students and visitors to the Centre, and serve to ensure that only the highest quality research is supported. In addition, these people can serve as a focus for the topical workshops which will form a vital part of the research activity of the Centre. The aim of such workshops is to concentrate the energies of a critical mass of researchers on a specific area of research of particular importance within the overall program of the Centre. Experience at similar Centres overseas suggests that workshops of this kind can often produce remarkable progress.

As part of the training activities of the Centre workshops will usually be preceded by a set of specialist, introductory lectures, lasting one or two weeks, aimed at bringing postgraduate students (from all over the country) to the point where they can participate fully in the workshop. We also aim to produce honours and postgraduate courses in nuclear and particle physics, quantum field theory and related areas that can be taken by students in their home institutions. As the first experiment in the production of such materials we are currently preparing a **CAUT application** through the University of Queensland which will involve the production of three courses (Statistical Mechanics at the University of Queensland, Advanced Quantum Mechanics at the University of Melbourne and Particle Physics at the University of Adelaide). These courses will be prepared by Profs. G. Milburn, B.H.J. McKellar and A.W. Thomas respectively, and will involve use of the World Wide Web, e-mail and video links. The overall responsibility for the project lies with Professor Milburn but it will operate through the Institute for Theoretical Physics in Adelaide. Further course development will follow after this initial exercise has been evaluated. We certainly intend to draw on the expertise of our overseas visitors in preparing this material.

The Centre will provide an **ideal environment for postgraduate and postdoctoral training**. All students will be encouraged to spend some period of their training working within an international collaboration. It is crucial that, as well as their training in mathematics, physics and information technology, they develop communication skills and a capacity to work both as part of a team and across international boundaries. In this way we can be sure to produce postgraduates and postdoctoral fellows, who will be extremely valuable in industry, ANSTO, CSIRO, DSTO and other research organizations.

3 SELECTION CRITERIA

3.1 Merit of Research Proposal

Research Excellence

• The Director of the Centre, Prof. A.W. Thomas FAA, is an ARC Senior Research Fellow and was awarded an ARC Special Investigator Award for 1996-98.
• The Deputy Director, Dr. A.G. Williams, currently holds two large ARC grants as well as honorary positions in the Department of Physics and the Supercomputer Computations Research Institute at the Florida State University, Tallahassee, USA.
• Both Principal Investigators have a record of proven productivity.
• **All** of the senior theorists working in this field in Australia are strongly supportive of the proposal and have joined it as Associates.
• The Principal Investigators already have an outstanding record of collaboration with visiting, overseas experts. These collaborative visits regularly produce tangible results in the form of publications in international refereed journals.
• Two of the first three Gold Bragg Medals of the Australian Institute of Physics have been awarded to students of Professor Thomas.
• Formal exchange agreements have already been signed with four key centres in the field: in China, Japan and Germany (2). Negotiations for further agreements are well advanced with major laboratories in France, Russia and the United States.

Potential for Advancement of Knowledge

• The Principal Investigators already have a strong track record of innovation and discovery.
• Within the Centre we shall assemble a world-class team which will share information from diverse approaches to the structure of hadronic matter.
• This is an ideal time for a concerted attack on the structure of hadronic matter. New laboratories such as CEBAF, RHIC and HERA are producing or are about to produce data in regions, and of a quality, never before available.
• Experience at comparable centres in North America and Europe suggests that a concentration of key researchers will often lead to a major advance in a field. For example, this was the purpose behind the creation of the Isaac Newton Institute in Cambridge, as it is for us.

Innovative Nature of the Proposal

• There is no comparable Centre for the study of hadronic matter in either the **Asia-Pacific region** or the southern hemisphere.
• Never before has the theoretical particle and nuclear physics community in Australia been so firmly committed to such a national centre.
• We shall encourage the participation (through workshops, postgraduate courses and Visiting Fellowships) of staff with relevant research interests from all Australian tertiary institutions, thus helping to build and maintain a strong network of theorists across the country.

Postgraduate Training and Education

• All postgraduates will be encouraged to spend a fraction of their training working within an international research team. In this way, as well as their training in mathematics, physics and information technology they will develop communication and teamwork skills which will make them extremely valuable employees on graduation.
• We shall draw on Associated Researchers and Visiting Research Fellows in developing honours and postgraduate courses for use across the country. The possibility of marketing these courses overseas will also be explored.

• Topical workshops will usually be preceded by a short course of lectures to enable postgraduate participants to benefit fully from the workshop itself.
• Subatomic physics has enormous power to stimulate the minds of young people and to draw them into tertiary study in science and mathematics – regardless of what they eventually choose as a career. Because of this we may hope to play a part in redressing the recent decrease in the number of able students choosing to study these areas.

3.2 Director and Associated Researchers

The Director, Professor A.W. Thomas, is an ARC Senior Research Fellow and was just awarded an ARC Special Investigator Award. He is one of the youngest Fellows of the Australian Academy of Science, having been elected at age 40. In the past two years he has accepted invitations to lecture at ten international conferences, workshops and postgraduate schools. His publication record includes more than 200 refereed articles in international journals and books. Professor Thomas has had extensive experience at major international centres including eight years in the Theory Group at the TRIUMF laboratory in Canada as a Senior Research Scientist, and three years as a staff member in the Theory Division at CERN (Geneva).

With respect to leadership qualities and management skills we note that Professor Thomas has:
• served as President of the Australian Institute of Physics (the national association of physicists with approximately 2,500 members) from 1991-93.
• been elected Head of Physics and Mathematical Physics at Adelaide University in 1988 and re-elected in 1991. This position required skills in personnel management and involved line responsibility for a budget of roughly $3M per year.
• served as a member of the Council of the University of Adelaide since 1991.
• served as Associate Dean of the Faculty of Science in 1986.
• served as Chair of the Physics and Mathematics Large Grant sub-panel of the ARC in 1994.
• been appointed to the European Advisory Committee of the European Centre for Theoretical Studies in Nuclear Physics (Trento, Italy). This is the European Centre directly comparable with our proposed Centre.
• acted as a co-organiser of two workshops at the Institute for Nuclear Theory in Seattle – the inaugural workshop in 1991 and again in 1996.
• been nominated by the C12 Committee as the next Honorary Secretary (1997-99) of the C12 Committee (Nuclear Physics) of the International Union of Pure and Applied Physics.
• been appointed to numerous international advisory committees in nuclear and particle physics.

The Deputy Director, Dr. Williams, has extensive experience in the United States, and still holds a courtesy appointment in the Department of Physics and in the Supercomputer Computation Research Institute at Florida State University. He currently serves as Director of the Institute for Theoretical Physics in Adelaide during the absence of Professor Thomas.

Finally, but most important, we emphasise the strength of commitment of all the senior theorists in Australia working in this field. There is a universal recognition of the importance of this Centre in developing a research network within Australia that will lift our international competitiveness to the highest level.

3.3 National Importance

• **The Strategic Plan for Physics** (*Physics : A Vision for the Future* (Feb. 1993)), prepared by the Australian Academy of Science at the request of the ARC, recognised the importance of establishing a National Institute for Theoretical Physics.

> **Recommendation 34 stated:**
> *A National Institute for Theoretical Physics should be established to coordinate a research network for theoretical physics. This would involve the universities, public sector research bodies and industry. It would organise formal visitor programmes and workshops and consolidate the theoretical base of experimental research programmes.*

• This Centre will fulfil the roles of the proposed Institute in nuclear and particle physics and quantum field theory.
• Never before has the theoretical physics community in Australia been so strongly behind a proposal for a national centre.
• In a competition conducted by the National Committee for Physics in 1994-95 a consortium led by the University of Adelaide, with Prof. Thomas as Director, was chosen on the advice of senior scientists at comparable institutes overseas.
• Since this decision more than two hundred theoretical and experimental physicists (including postgraduates) from around Australia have attended five very successful workshops at the Institute in Adelaide. There could be no better illustration of the need for the proposed Centre.
• The programs already conducted have led to new and enhanced collaboration within Australia. They have attracted senior scientists from overseas (e.g. France, Japan, Germany and the United States) and led to new collaborations with these people.
• Involvement in the research activities of the Centre will serve to **stimulate and re-vitalize** isolated theorists, thereby raising the overall standard of theoretical physics in Australia.
• The Centre will also provide important stimulus and support for Australian experimental work in high energy and nuclear physics.
• The Centre will be a magnet to key people in hadronic physics throughout the world.
• The Centre will produce highly skilled graduates and postdoctoral fellows capable of working in high technology industry as a part of multi-national teams.

3.4 International Links

- Our plans to establish a Centre for the Subatomic Structure of Matter have already received enthusiastic support in the international community - notably in China, France, Japan, Germany, Russia and the United States. (Examples of the **letters of support** can be provided on request.)

- Already a number of senior, overseas theorists have expressed a keen interest in attending workshops planned in 1997 in hadronic physics.

- We stress that we already have strong and productive research links with major research centres and laboratories.

- Formal exchange agreements, *which have already led to research grants, the exchange of students and senior staff and joint publications*, have been signed with four major centres of nuclear and particle physics. Numerous other agreements will be signed this year. *In every case these agreements are firmly based in existing collaborations.*

- It is clear from the correspondence we have had that this Centre will take its place as one of the leading research centres in the world in strong interaction physics.

3.5 End-user Support and Cooperation

The prime purpose of this Centre is to conduct basic research of the highest quality. It is not created to generate new technology within the next decade. On the other hand, we are committed to a number of goals that should be of immediate practical value.

1. As explained a number of times we shall place an emphasis on producing extremely useful graduates and postdoctoral fellows, with international experience and skills in communication and team-work as well as physics, mathematics and computing.

2. Whenever senior overseas scientists visiting the Centre have skills or knowledge of value to industry and/or government research organizations we shall make every effort to ensure productive contact. Existing DSTO support for the Institute is based on this - as well as the highly skilled graduates of course. Our efforts to ensure a significant level of long term funding from sources outside academia will rely in part on our success in this area.

3. The involvement of Centre staff in major overseas laboratories will give us very early access to new technology - particularly in information technology; e.g., the World Wide Web was developed at CERN. If we can speed the transfer of such leading edge technology to Australian industry the financial benefits could be enormous.

3.6 Host Institution Support

The essential infrastructure for the Centre already exists. The University of Adelaide has already provided support in cash and kind (space at 10 Pulteney Street) worth approximately $200k in 1995 and 1996. The Government of South Australia has already provided $130k.

During the lifetime of the Centre, the University will continue to provide all the necessary infrastructure support, including accounting and library services, insurance, mail, telephones, access to the CM-5 parallel computer, internet services and appropriate space free of charge.

In addition, the University of Adelaide will provide:

- the salary of the Director
- the salary of the Deputy Director (0.5 time)
- a replacement (in the research field of the Centre) at lecturer level for the teaching duties of the Director
- a cash contribution of $50k per annum

3.7 Management and Structure

The University of Adelaide and the Flinders University of South Australia have agreed to establish the **South Australian Institute for Theoretical Physics** as a formal University Centre. This Institute has a broader aim of encouraging collaboration between all theoretical and mathematical physicists in S.A. as well as fundraising. Final approval is expected at the

April meeting of the Council of the University of Adelaide. **For the forseeable future the Special Research Centre for the Subatomic Structure of Matter will be the major research activity of the S.A. Institute.**

The Management Committee of the S.A. Institute comprises:
1. the Director (Prof. A.W. Thomas FAA)
2. the Deputy Director (Dr. A.G. Williams)
3. four members elected at the Annual General Meeting
4. Prof. M. O'Kane FTS, DVC Research, University of Adelaide
5. Prof. J. Skinner, Pro-VC Research, Flinders University (or nominee)
6. Dr. M. Golley (Chief High Frequency Radar Division, DSTO)
7. One additional member if desired.

This Management Committee will meet at least once per year.

The **Centre for the Subatomic Structure of Matter** will have a more specialised Advisory Board to provide advice to the Director. The membership will be:
Prof. M. O'Kane FTS
Prof. I. Kotlarski, Dean of Science, University of Adelaide
Prof. A.W. Thomas FAA
Dr. A.G. Williams
A. Prof. I.R. Afnan (Flinders University of S.A.)
Prof. B.H.J. McKellar FAA (University of Melbourne)
Prof. R. Delbourgo FAA (University of Tasmania)

In addition, we propose to appoint key researchers in senior management positions at comparable centres overseas as external members of the Advisory Board. While most of the business of this Board can be conducted by e-mail and telephone it is proposed to have one major meeting each year with the foreign advisers present.

The Director of the Centre will be formally responsible to the Dean (and Head of Division) of Science, with the Centre itself located within the Department of Physics and Mathematical Physics of the University of Adelaide. All accounting will be carried out within the existing Departmental system.

4 ADDITIONAL REQUIREMENTS

4.1 Performance Objectives

The Centre will have a **strong research program**, evidenced by :
• high quality, well-cited publications in international, refereed journals.
• invitations to present the work of the Centre at international conferences, workshops and schools.
• attracting leading researchers in the field from overseas for extended periods. This should lead to **tangible** results in terms of joint refereed publications.
• attracting high quality research staff and postgraduate students.

The centre will **serve as a focus for the Australian theoretical physics community**. Suitable indicators include:
• participation in joint research projects with staff of the Centre and Visiting Research Fellows.
• participation in topical workshops held at the Centre by both academic staff and postgraduate

students.
• willingness of academic staff to spend extended periods as Visiting Fellows within the Centre.

The Centre will **maintain and improve its links with major centres** of theoretical physics and experimental laboratories.

These links should involve:
• exchange of personnel, including postgraduate students.
• joint research projects leading to publication.
• participation in the planning and analysis of experiments aimed at elucidating features of the subatomic structure of (hadronic) matter.
• joint planning and organization of topical workshops in fields of mutual interest.

4.2 Potential for Generating Additional Funds

As discussed elsewhere in the proposal **we have already been successful in generating very significant funds** from the University of Adelaide, Flinders University, the Government of South Australia ($130k) and DSTO. It is anticipated that, at least in the initial years, 50% of funds commited to the Institute will be available as cash for the research programs of the Centre. In addition, support from Digital Equipment Corporation means that we already have almost $200k in modern computing equipment in the Centre – in addition to the facilities in the Department (which are excellent).

For the future we are working with Michels Warren (Sydney) on an approach to private industry for long-term funding of Theoretical Physics. This is initially a twelve month commitment on their part, at no cost to the Institute. We have also outlined plans to raise the awareness of Theoretical Physics amongst the general public, industry and government research organizations. This is intended to build a support base for long-term funding.

There is also considerable potential for generating research funds through our international links. We have already cited a joint research grant with the group in Bonn and Jülich, funded by DFG. We shall also seek funding for exchanges and workshops through the bilateral programs of DIST. Finally, we already have expressions of interest from some overseas laboratories (e.g, IUCF and Saclay) in sharing the costs of workshops at the Centre on topics of mutual interest.

5 EXPLANATION OF BUDGET

ARC Component

• It will be essential to appoint two **Senior Research Associates** to complement the expertise of the Principal Investigators (PI's) in fields such as QCD sum-rules, lattice gauge theory and light-cone field theory.
• The **Research Associates** will assist the PI's, the Senior Research Associates and various Research Fellows and visitors in assuring timely completion of research projects suited to their skills.
• It is absolutely vital that the Centre have first-class computing support - for large-scale numerical and algebraic calculations, internet support, visitor training, system maintenance, back-up and upgrades, etc. This will require a full-time **Computing Officer**.
• In addition to a **full-time administrative assistant** it will be essential to have **part-time assistance** for the additional load associated with workshops.

• We expect to have Australian collaborators working at the Centre as **Senior Visiting Fellows** for extended periods. On average the support for such positions is costed at the salary of one full-time Reader.

• Although most students will be expected to win APRA's, these are so oversubscribed that even some first-class honours students miss out. **Student Scholarships** are accorded priority A because of the importance we place on postgraduate training.

• The **Workshop costs** are based on past experience of the costs of running an intensive, two-week, topical workshop involving 30-40 people. This includes travel and living costs for post-graduate students and staff from interstate.

• **Travel** includes the cost of travel for members of the Advisory Board, as well as travel by staff of the Centre to national and international conferences.

• **Maintenance** includes photocopier, fax, paper costs as well as computer and software contracts.

• We have stressed the importance of being able to support the travel and living costs of outstanding researchers outside of Australia for periods of one or more months. Based on recent experience we have costed these **Visiting Research Fellows** as 10 visitors for one month, at $7.5k each and two visitors for 6 months, at $20k each.

• **Equipment** includes replacing and upgrading workstations, X-terminals, printers, etc.

Partner Component

The University of Adelaide will pay the full salary and on-costs for the **Director** for the duration of the Centre. The **Deputy Director** will devote 50% of his time to the research program of the Centre. The Dean of Science has committed $50k per annum in cash which, as agreed by the Head of Physics and Mathematical Physics, will be used to hire a **contract lecturer** to replace the teaching of Prof. Thomas. The research field of the appointee will be that covered by the Centre, thus significantly **enhancing its program**.

In 1995 the University of Adelaide received a gift of US$350k to create the **Biedenharn Fellowship** – in memory of Prof. L. Biedenharn. The interest on this sum (above inflation) will help to fund the participation of the Biedenharn Fellow in the research program of the Centre.

The **additional $75k cash from partners** consists of $50k from the DVC Research (University of Adelaide) and 50% of contributions to the S.A. Institute from DSTO and the Flinders University. Additional funds raised (e.g., through the efforts of Michels Warren) will be used to supplement the line for overseas visiting experts.

Related Research Grants

Both of the PI's currently hold Large ARC grants for projects which complement the research program at the Centre. These grants are for a very specific purpose and **short-term** and therefore cannot substitute for a long-term, coherent, SRC-supported research **program**. Such a concerted program is essential if we are to make a major step forward in the very difficult problem of solving the structure of strongly interacting systems. Nevertheless, the work carried out at the Centre and under the specific ARC projects will be mutually beneficial.

6 CURRICULUM VITAE: DIRECTOR

Prof. Anthony W. Thomas, FAA

Current Employment: Elder Professor of Physics, University of Adelaide *and* ARC Senior Research Fellow (until 11/96).

Nationality: Australian **Date of Birth:** November 15, 1949.

Awards:

ARC Special Investigator Award 1997-
ARC Senior Research Fellow 1991-96
Inoue Fellowship (Japan) 1993
Alexander von Humboldt Forschungspreise 1992
Inaugural Silver Jubilee Convocation Medal of the Flinders University of SA 1991
Elected Fellow of the Australian Academy of Science 1990
Elected Fellow of the American Physical Society 1987
Walter Boas Medal of the Australian Institute of Physics 1987
Doctor of Science, The University of Adelaide (1986)

Previous Employment:

Killam Postdoctoral Fellow, University of British Columbia (9/73 to 8/75)
Paid Scientific Associate, CERN (on leave from TRIUMF) (9/75 to 8/76)
Senior Research Scientist, TRIUMF, Vancouver (9/75 until 2/84)
Staff Member, Theory Division, CERN, Geneva (2/82 - 2/84)

Recent Academic Posts:

Member, European Advisory Committee for the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (Trento) 1996-
Vice-President, Australian Academy of Science 1994-95
Chair, Mathematical and Physical Science sub-panel of the ARC 1994
Member, Commission C12 (Nuclear Physics), International Union of Pure and Applied Physics (IUPAP) 1994-96
Member, Editorial Board, The Australian Journal of Physics 1994-98
Chair, CERN Consortium Advisory Board 1994-96
Editor, Progress in Nuclear and Particle Physics (Pergamon) 1993-97
Chair, Strategic Plan Implementation Committee of the AIP 1993-
Leader, Australian Delegation to the IUPAP General Assembly 1993 and 1987
Member, Advisory Committee, International Institute of Theoretical and Applied Physics, Iowa State University 1993-
Chair, CERN Coordination Committee, ANSTO 1991-93
Member of Council, Australian Academy of Science 1992-95
Member, Physical Sciences Large Grant panel of the ARC 1991-1994
President of the Australian Institute of Physics 1991-93
Member of Council, the University of Adelaide 1991-99
Head, Department of Physics and Mathematical Physics 1988-91
Member, International Advisory Committee, Int. Conf. on Particles and Nuclei 1990-
Associate Dean, Faculty of Science, University of Adelaide 1986
Member, International Advisory Committees for 15 International Schools and Conferences since 1990
Member, International Advisory Committee, Int. Conf. on Few Body Problems 1978-

ARC Large Grants (since 1989):

1996-98: Special Investigator Award: \$ 200,000 per annum;
1993-95: \$ 150,000, \$ 154,700, \$158,400;
1989-92: Program Grant: \$105,821, \$ 110,371, \$ 116,200, \$128,000.

Postgraduate Student Supervision:

Since 1990 eight students have successfully obtained an M.Sc. or Ph.D. under my supervision (as well as 6 honours students). Two of the Ph.D.graduates (Dr. S.D.Bass 1992 and Dr. W. Melnitchouk 1994) were awarded the Gold Bragg Medal of the Australian Institute of Physics for the best Ph.D. thesis in Australia in their year of graduation. At present I am supervising 5 Ph.D., 1 M.Sc. and 2 Hons. students.

Invited Presentations at International Conferences and Schools:

Since 1989: accepted 14 invitations to speak in plenary session at major International Conferences and Workshops (4 in **1995** and 4 in **1994**); accepted a further 7 invitations to lecture at International Post-Graduate Schools (including, Brasil, Canada, France, Japan, The Netherlands, Italy and Taiwan).

Publications:

More than 210 refereed papers published in books and journals. Editor of one post-graduate text book, *Modern Three Hadron Physics*, Springer **1977**. Editor with D.F. Measday of Proc. 8th Int. Conf. on High Energy Physics and Nuclear Structure (Nucl. Phys. **A335, 1980**). It is not possible to show in the two pages permitted for CV and publications more than a small fraction of my recent publications. Since 1989 I have published the following number of refereed papers in the corresponding year (more details can be provided on request, or check: http://www.physics.adelaide.edu.au/theory/home.html): **1989** 9; **1990** 8; **1991** 12; **1992** 9; **1993** 10; **1994** 16; for the latest full year, **1995** 20. The most recent which will fit are:

195. F.M. Steffens, H. Holtmann and A.W. Thomas, *Mesonic corrections to the shape of quark distributions*, Phys. Lett. **B358**, 139-145, **1995**.

196. W. Melnitchouk and A.W. Thomas, *Meson Cloud of the Nucleon in Polarized Semi-Inclusive Deep-Inelastic Scattering*, Zeit. Phys. **A353**, 311-319, **1995**.

197. W. Melnitchouk and A.W. Thomas, *Q2 Dependence of Nuclear Shadowing*, Phys. Rev. **C52**, 3373-3377, **1995**.

199. K. Saito and A.W. Thomas, *Composite Nucleons in scalar and vector mean-fields*, Phys. Rev. **C52**, 2789-2791, **1995**.

200. J. Haidenbauer, K. Holinde, K. Kilian, T. Sefzick and A.W. Thomas, *Weak Strangeness Production in Nucleon-Nucleon Scattering*, Phys. Rev. **C52**, 3496-3500, **1995**.

201. K. Saito and A.W. Thomas, *Effect of Nucleon Structure Variation in Super-allowed Fermi Beta-decay*, Phys. Lett. **B363**, 157-161, **1995**.

202. J.T. Londergan, G.Q. Liu, E.N. Rodionov and A.W. Thomas, *Probing the Pion Sea with p-D Drell-Yan*, Phys. Lett. **B361**, 110-114, **1995**.

203. A.W. Thomas and K. Saito, *Charge Symmetry Violation in Nuclear Physics*, in Weak and Electromagnetic Interactions in Nuclei, H. Ejiri et al., editors (World Scientific, Singapore, **1995**), pp. 495-503.

204. F.M. Steffens and A.W. Thomas, *The Role of Strange and Charm Quarks in the Nucleon Spin Structure Function*, Phys. Rev. **D53**, 1191-1208, **1996**.

205. S.D. Bass and A.W. Thomas, *A New Hypothesis on the Origin of the Three Generations*, Mod. Phys. Lett. **A11**, 339-347, **1996**.

A further 14 papers have already been accepted for publication in refereed publications in **1996**, while 6 more are in preparation for submission.

7 CURRICULUM VITAE: DEPUTY DIRECTOR

Dr. Anthony G. Williams

Current employment:
Senior Lecturer (Tenured), Dept. of Physics and Math. Physics, University of Adelaide
Nationality: Australian citizen **Date of Birth:** November 11, 1955
Qualifications:
– Ph.D. in theoretical physics, May 1, 1985. (Flinders University of S.Aust.)
– Bachelor of Engineering (Electrical)(Honours), University of Adelaide, 1981.
– Bachelor of Science (Mathematical physics)(Honours), University of Adelaide, 1980.
Honours: Fellow of the Australian Institute of Physics (awarded 1992).
Principal Research Interests: Theoretical, Computational, and Mathematical Physics. Specialization in theoretical nuclear and particle physics
Employment History:
– Senior Lecturer, Dept. of Physics and Math. Physics, Univ. of Adel., (1995 - present)
– Courtesy appointment, Depart. of Physics, Florida State Univ., USA (1994 – present)
– Lecturer, Dept. of Physics and Math. Physics, Univ. of Adel., (1993 - 1994);
– Assoc. Prof. , joint appointment in the Depart. of Physics and the Supercomputer Computations Research Institute (SCRI), Florida State Univ., USA. (1993);
– Assistant Professor, Florida State University, (1989-1992);
– Postdoc. Res. Assoc. (1986 - 1989), Depart. of Physics, Univ. of Washington, USA
– Postdoc. Res. Assoc. (1984 - 1986), Depart. of Physics, Univ. of Adelaide, Adelaide.
– Research Scholarship (1981 - 1984), Flinders University of S. Aust.
Postgraduate Student Supervision: I am currently supervising 4 Ph.D. students.
Invited Talks: Five invited talks at international conferences and workshops since 1994.
RESEARCH GRANTS (only most recent shown)
5) Sole PI on ARC large grant "Covariant Models of Hadron Structure" (A69231918, Aus$56,000 per annum, 1993-1995).
6) Co-PI with A.W. Thomas on ARC small grant "Application of QCD Sum Rules to Nuclear Structure" (Aus$12,000, 1995).
7) Sole PI on ARC large grant "Electromagnetic Probes of the Strong Interaction" (A69532047, Aus$52,000 per annum, 1995-1997).
8) Co-PI (with B.H.J. McKellar and T. Kieu at the U. of Melbourne) on ARC large grant "Studies of Lattice Gauge Theory" (A69532047, Aus$89K, Aus$126K, Aus$100K respectively for 1996, 1997, 1998).
9) Sole PI on ARC small grant "Covariant Models of Hadron Structure" (Aus$18,000 for 1996).
PROFESSIONAL SERVICE
–Referee for: Phys. Rev. Lett., Phys. Rev. C, Phys. Rev. D, Phys. Lett. B, Nucl. Phys. A, J. Phys. A, J. Phys. G, Int. J. Mod. Phys. A, Mod. Phys. Lett. A.
–Proposal reviewer for: Aust. Res. Council, U.S. Dept. of Energy, U.S. Nat. Sci. Found.
–Secretary for the Australian Institute of Physics (South Australian Branch) 1994-1995.
–Co-organizer of joint CEBAF/Florida State University nuclear theory workshops [1990 (FSU), 1991 (CEBAF), 1992 (CEBAF)]
–Member of International Scientific Advisory Committee for the *International Conference on Computational Physics*, December 5-9, 1995, Taiwan.
–Member of organizing committee for the *Nonperturbative Methods in Field Theory* Workshop, May 1 - July 7, 1995, Australian National University, Canberra, Australia.
–Scientific Secretary and co-organizer for the Joint Japanese-Australian Workshop on *Quarks,*

Hadrons, and Nuclei at the Adelaide Institute of Theoretical Physics, University of Adelaide, November 15-24, 1995.

REFEREED PUBLICATIONS

Edited Books and Conference Proceedings:

1) Proceedings of the "Quarks, Hadrons, and Nuclei Workshop", Adelaide, Australia, 1995. Edited by K. Saito, A.W. Thomas, and A.G. Williams. To appear in the Australian Journal of Physics.

Recent Publications in Refereed Journals (most recent 14 of 41):

28) "Medium modification to the ω-meson mass in the Walecka model" by H.-C. Jean, J. Piekarewicz, and A.G. Williams, Phys. Rev. C **49**, 1981-1988 (1994).

29) "Dynamical chiral symmetry breaking and confinement with an infrared vanishing gluon propagator?" by F.T. Hawes, C.D. Roberts, and A.G. Williams, Phys. Rev. D **49**, 4683-4693 (1994).

30) "Dyson-Schwinger equations and their application to hadronic physics" by C.D. Roberts and A.G. Williams. Chapter 7 in *Progress in Particle and Nuclear Physics, Vol. 33*, Amand Faessler (Ed.), pp. 477-575, (Pergamon Press, Oxford, 1994).

31) "Constraints on the momentum dependence of rho-omega mixing" by H.B. O'Connell, B.C. Pearce, A.W. Thomas, and A.G. Williams, Phys. Lett. B **336**, 1-5 (1994).

32) "Relativistic quark-antiquark bound state problem with spin-dependent interactions in momentum space" by H.-C. Jean, D. Robson, and A.G. Williams, Phys. Rev. D **50**, 5873-5877 (1994).

33) "Chiral symmetry breaking in quenched massive strong coupling four-dimensional QED" by F.T. Hawes and A.G. Williams, Phys. Rev. D **51**, 3081-3089 (1995).

34) "Solving the Bethe-Salpeter equation for scalar theories in Minkowski space" by K. Kusaka and A.G. Williams, Phys. Rev. D **51**, 7026-7039 (1995).

35) "Rho-omega mixing, vector meson dominance, and the pion form factor" by H.B. O'Connell, B.C. Pearce, A.W. Thomas, and A.G. Williams. University of Adelaide preprint ADP-95-1/T168, bulletin board hep-ph/9501251. To appear in *Trends in Particle and Nuclear Physics*, edited by W.Y.P. Hwang (Plenum Press).

36) "Rho-omega mixing and the pion electromagnetic form-factor" by H.B. O'Connell, B.C. Pearce, A.W. Thomas, and A.G. Williams, Phys. Lett. B **354**, 14-19 (1995).

37) "Pion form factors at intermediate momentum transfer in a covariant approach" by A. Szczepaniak and A.G. Williams, Int. J. Mod. Phys. **A11**, 655–676 (1996).

38) "Vector meson mixing and charge symmetry violation" by H.B. O'Connell, A.G. Williams, M.E. Bracco, and G. Krein. Preprint number ADP-95-49/T196, Los Alamos archive hep-ph/9510425. To appear in Phys. Lett. B.

39) "Solving the Bethe-Salpeter equation in Minkowski space: scalar theories and beyond" by K. Kusaka, K.M. Simpson, and A.G. Williams. To appear in the Aust. J. Phys.

40) "Structure Functions of the Nucleon in a Covariant Scalar Spectator Model" by K. Kusaka, G. Piller, A.W. Thomas, and A.G. Williams. To appear in the Aust. J. Phys.

41) "Analysis of rho-omega mixing and interference in the pion form-factor" by K. Maltman, H.B. O'Connell, and A.G. Williams. Preprint number ADP-95-50/T197, hep-ph/9601309. To appear in Phys. Lett. B.

Refereed Papers in Conference Proceedings etc.:

There are 16 refereed publications in conference proceedings (not listed for brevity).

8 ADDITIONAL REFEREES

Every senior researcher in the field in Australia has commited to participating in the research program of the Centre. While we view this as a strength of the program, it may complicate its review. We therefore provide a list of senior theorists (including key people at the comparable national or regional centres in Europe and the United States) who could provide an informed evaluation of the PI's and the science:

1. Prof. D. Brink,
   Vice-Director, ECT,
   Strade delle Tabarelle 286,
   I-38050 Villazzano (Trento)
   ITALY
   Fax: + 39-461-935007
   e-mail: brink@ect.unitn.it
   (In **August only** Prof. Brink's address will be:
   Dept. of Theoretical Physics,
   Oxford University
   1 Keble Road
   Oxford OX1 3NP
   United Kingdom
   Fax: + 44-1865-273947
   email: as above)
   • Senior Nuclear theorist and Vice-Director of the European Centre for Nuclear Theory.

2. Prof. T. Matsui,
   Deputy Director,
   Yukawa Institute for Theoretical Physics,
   Kyoto University,
   Kyoto 606-01
   JAPAN
   Fax: + 81-75-753-7010
   e-mail: matsui@yukawa.kyoto-u.ac.jp
   (In **July and August only** Prof. Matsui's address will be:
   Institute for Theoretical Physics,
   University of Erlangen-Nürnberg,
   Staudtstrasse 7,
   91058 Erlangen
   GERMANY
   • Senior Nuclear Theorist at the Yukawa Institute - the major centre for theoretical physics in Japan.

3. Prof. W. Haxton, Director
   or
   Prof. E. Henley, Deputy Director
   Institute for Nuclear Theory,
   University of Washington,
   Seattle, 98195

USA
Fax: + 1-206-685-0635
e-mail: haxton@gamow.npl.washington.edu
henley@alpher.npl.washington.edu
• These are both senior, nuclear theorists in charge of the major centre for nuclear theory in the United States.

4. Prof. J.T. Londergan,
Head, Department of Physics,
Indiana University,
Bloomington. IN 47405
USA
Fax: + 1-812-855-5533
e-mail: londergan@venus.iucf.indiana.edu
• Senior nuclear theorist working at the Indiana University Cyclotron Facility as well as Head of Physics.

5. Prof. T. Goldman,
Theoretical Division, T-5/MS-B283
Nuclear Theory Group,
Los Alamos National Laboratory,
PO Box 1663, Los Alamos. NM 87545
USA
fax: + 1-505-667-1931
e-mail: goldman@t5.lanl.gov
• Senior nuclear theorist, Head of the nuclear theory group at Los Alamos Laboratory.

9 LETTERS OF SUPPORT

As noted in the body of the proposal we would be happy to provide copies of the numerous letters of support for this project that we have received from major centres around the world.