Few-Body Systems

Editor in Chief: W. Plessas, Graz

Supplement 15

Nuclear Dynamics: From Quarks to Nuclei

Proceedings of the XXth CFIF Fall Workshop,
Lisbon, Portugal, October 31–November 2, 2002

Edited by
M. T. Peña, A. Stadler, A. M. Eiró, and *J. Adam*

Springer-Verlag Wien GmbH

Prof. Dr. M. Teresa Peña
Centro de Física das Interaccoes Fundamentais
Instituto Superior Técnico
Lisboa, Portugal

Prof. Dr. Alfred Stadler
Departamento de Física, Universidade de Évora
Lisboa, Portugal
and
Centro de Física Nuclear, Universidade de Lisboa
Lisboa, Portugal

Prof. Dr. Ana M. Eiró
Centro de Física Nuclear, Universidade de Lisboa
Lisboa, Portugal

Dr. Jiří Adam
Institute of Nuclear Physics
Řež, Czech Republic

Originally published by Springer-Verlag Wien New York in 2003
Softcover reprint of the hardcover 1st edition 2003

Typesetting: Camera-ready by authors

Printed on acid-free and chlorine-free bleached paper
SPIN: 10899687

With 106 Figures

CIP data applied for

ISSN 0177-8811
ISBN 978-3-7091-7301-5 ISBN 978-3-7091-6014-5 (eBook)
DOI 10.1007/978-3-7091-6014-5

Dedicated to Peter Sauer
on the Occasion of His 65th Birthday

Organizing Committee

M. Teresa Peña, CFIF–Instituto Superior Técnico, Lisbon
Alfred Stadler, CFNUL–University of Lisbon and University of Évora
Ana M. Eiró, CFNUL–University of Lisbon
Jiří Adam, Nuclear Physics Institute, Řež–Prague

Invited Speakers

- G. Baym (Urbana-Champaign)
- S.A. Coon (Department of Energy)
- F. Gross (JLab)
- A.C. Fonseca (Lisbon)
- B. Frois (Min. Recherche, Paris)
- H. Garcilazo (Mexico City)
- J. Haidenbauer (FZ Jülich)
- J.-M. Laget (Saclay)
- T.-S.H. Lee (Argonne)
- L. Marcucci (Pisa)
- G.A. Miller (INT Seattle)
- W. Plessas (Graz)
- D.O. Riska (Helsinki)
- R. Schiavilla (ODU and JLab)
- I. Sick (Basel)
- R. Timmermans (KVI Groningen)
- J.A. Tjon (Utrecht and JLab)
- A. Valcarce (Salamanca)

Secretariat

Sandra Oliveira and Dulce Conceição
Department of Physics, Instituto Superior Técnico, Lisbon

Sponsored by

Fundação para a Ciência e a Tecnologia
Fundação Calouste Gulbenkian
Banco Português de Investimento (BPI)
Grupo Teórico para as Altas Energias (GTAE)
Centro de Física das Interações Fundamentais (CFIF)
Centro de Física Nuclear da Universidade de Lisboa (CFNUL)

Foreword

This volume collects the invited and contributed papers presented[†] at the workshop *Nuclear Dynamics: from quarks to NUCLEI*, which was hosted by Centro de Física das Interacções Fundamentais (CFIF) at Instituto Superior Técnico (IST) in Lisbon, Portugal, from October 31st to November 2nd, 2002. The response to this initiative exceeded the initial expectations of the organizers. Participants arrived to Lisbon, not only from countries within a close vicinity to Portugal, but also from Central and Northern Europe, from Africa, from the United States, from South and Central America, and from Japan.

This meeting was the 20th in a series of schools or workshops organized every fall in Lisbon. Along the years, the series of meetings has covered a wide range of topics in Nuclear and Particle Physics. The 2002 meeting had two unique features:

1) Nuclear Physics at Intermediate Energies

For the first time, the CFIF Fall Meeting focused on nuclear processes at intermediate energies. In physics, an energy range implies a selection of the degrees of freedom which are probed. Experiments and theory at intermediate energies bridge the interesting border between two pictures of reality: the nucleons, and their accompanying cloud of pions, which make up the nuclei forming most of the matter around us, and the underlying quark-gluon structure of the nucleons themselves. The intriguing connection between the two descriptions is tested by experiments using electrons, photons and mesons, or heavy-ion collisions. Throughout the workshop, several talks reported on the latest news from these experimental observations, other talks presented attempts of their theoretical interpretation.

The meeting was organized in the following 10 scientific sessions (in chronological order): *Electroweak Probes (I)* (chair M. T. Peña), *The Nuclear Interaction* (chair A. Arriaga), *Meson Production from Light Nuclei* (chair J. Adam), *Electroweak Probes (II)* (chair George Rupp), *The Nuclear Medium Under Extreme Conditions* (chair J. Dias de Deus), *Constituent Quark Models and Chiral Symmetry* (chair M. Fiolhais), *Relativity and Electromagnetic Observables* (chair F.D. Santos), *Non-Nucleonic Degrees of Freedom* (chair P.U. Sauer), *Relativity, Chiral Symmetry, and Form Factors of Baryons and Mesons* (chair A. Stadler), and *Nuclear Structure and Binding* (chair R. Timmermans).

This scientific program paid special attention to photonuclear, electroweak, and meson production reactions with light nuclei, measured at Jefferson Laboratory (JLab, Virginia), FZ-Jülich (Germany), Mainz (Germany), and MIT-

---

[†] With the exception of the talks by S.A. Coon, R. Timmermans and G. Baym who, regrettably, could not provide a written version of their presentations.

Bates (Massachussets), as well to possible future measurements of new neutrino reactions at Fermilab (Illinois) and KEK (Japan), and heavy-ion collisions results from RHIC (New York).

Specifically, the problem of the structure of nuclei and nucleons was considered and recent electron-nucleus scattering data from JLab, taken at momentum transfers in regions up to $Q^2 = 4\ \mathrm{GeV}^2/\mathrm{c}^2$, were presented to the audience. In this context, possibilities and difficulties of disentangling meson-exchange-current contributions from final state interactions were discussed. Additionally, models attempting to describe the baryon spectra and the new baryon form factor data from JLab were shown, and with this respect the role of relativity and the importance of the pion cloud effects were particularly discussed.

Furthermore, the meeting highlighted very recent observations exploring the regime of high momentum transfer in the deep inelastic scattering experiments at HERMES, and the extreme nuclear densities in the heavy-ion collisions at RHIC. The drastic suppression of away-side jets seen in the STAR data will eventually help to filter out theoretical models. Long after the first minutes of the Universe, and far away from exotic stars, this kind of experiments may reveal how the transition between nucleonic and deconfined quark state matter occurs.

2) A Tribute to Peter Sauer

The workshop was also the stage for a tribute to Peter Sauer, and a special session was dedicated to him, on the occasion of his 65th birthday. Peter Sauer finished his Ph.D. in Physics in 1966, at the University of Freiburg/Breisgau, with a thesis in Solid State Physics. After obtaining his Ph.D., he left Germany for research associate positions at Carnegie-Mellon Pittsburg and MIT. He then redirected his research activities to Nuclear Physics. After working on ground-state properties of nuclei in the framework of Hartree-Fock-Bogoliubov and Bruckner theory, and on the nuclear-shell model, Peter decided to approach the complexity of nuclei through the power of exact calculations, which test and control approximations. He focused in particular on few-nucleon dynamics. In 1974, he returned to Germany and settled down at the University of Hannover, determined to place it on the world map of research in Nuclear Physics. Since then, and well before the present era of globalization and networking in science, he established international links and collaborations within Europe, the United States, Japan and Brazil.

Some Impressions on Peter Sauer's Personality

Maybe not too common for a theorist, Peter Sauer always had a strong personal interest in other people, and an eagerness for seizing opportunities and making new life experiences, which is also reflected in his intense international activities. It relates also to his pleasure in traveling and in the arts. For him, art and philosophy are preferred means to aleviate the sometimes heavy burden of the routines of everyday life. We still remember his remarkable speech at the conference banquet of the XVIIth European Few-Body Conference in Évora in 2000, where, inspired by Goethe's *Faust*, he described episodes in the life of physicists and of the emerging European Union with elegance and philosophical strokes of humour.

With family roots in Eastern Europe, more precisely, born in Breslau (in Silesia, in former East Germany and at present part of Poland), and with a diverse professional activity in the United States, Peter Sauer became clearly a man where two cultures (the west and the east) are interwoven. Although he acts very often with an open and relaxed American style, his eastern origins surface occasionally. For instance, when he got involved in European programs in support of teaching at undergraduate and at graduate levels, he paid particular attention to Eastern Europe. As a co-founder of the European Mobility Scheme for Physics Students, he was the Coordinator for several TEMPUS Programs of Students Exchange, which were specific for students from Central and Eastern Europe.

One of us (M.T.P.) will never forget the day in the fall of 1989 shortly after the profound political changes, when Peter rushed with her, a junior postdoc at the time, across East-Berlin, where the wall was still standing. Peter knew that it was her unique opportunity to witness important changes in Europe right at their epicenter. History was moving very fast. Peter wanted her to still be able to see the best pieces of the historical and artistic graffiti on the Berlin wall. They were to be found in the quarter of Kreuzberg. Naturally, it was far away from the city center, but very close to the watch towers and barbed-wired fences, then still standing like threatening symbols of oppression. It was clear how Peter had longed to go unrestrictedly to this side of the former border.

A Brief Sketch of Peter Sauer's Scientific Work

Peter Sauer was involved, very often side by side with experimentalists, in projects related to microscopic nuclear structure, in particular in experiments that serve as windows to sub-baryonic degrees of freedom (e.g., the Saclay experimental program of the 80's on intermediate energies and few-nucleon targets). One can fairly say that in almost all issues discussed in this meeting, Peter Sauer gave over the years, important and timely contributions. Bernard Frois reminded us of this during his talk in the closing session. Specifically, he emphasized the value of the Hannover group calculations of the electromagnetic structure of ^{3}He and ^{3}H, which revealed clearly the hitherto hidden importance of non-nucleonic degrees of freedom in those nuclei.

Peter Sauer showed often the ability to contribute to his field ahead of time, and not always following the main stream. Illustrations of his leadership are, for instance, his 1975 paper on the role of the neutron charge form factors in electron scattering from the three-nucleon system; his plenary talk, at the 1976 International Conference on Few-Body Problems in Dehli, on the Coulomb problem in few-nucleon systems, with the intention of studying the charge asymmetry and charge dependence properties of the nuclear force; his contributed talk at the same conference where he expanded on trinucleon properties derived from one-boson-exchange potentials, which were still in their infancy. At this point a very special emphasis is due to the comparison between Faddeev and variational three nucleon calculations performed by his group in 1981, in a paper demonstrating the reliability of momentum-space solutions of the Faddeev equations.

As further relevant work of Peter Sauer we mention the study on meson exchange currents and tritium beta decay, published by his group in 1991 and the paper on the radius of the deuteron which, in 1996, established quantitatively the hierarchy of importance of sub-baryonic degrees of freedom (from the meson exchange contributions down to the quark-gluon sub-structure of the nucleon). This Hannover group calculation, at the same time, was able to discriminate between the existing experimental data for the deuteron charge radius, from elastic scattering and atomic physics experiments, favoring the latter one. In 1997, the group also published results on polarized deep inelastic lepton scattering from polarized two and three nucleon bound states. In that work, the Hannover calculations on few-nucleon dynamics, including relativity, provided the appropriate subtraction of nuclear effects, which is necessary to extract the neutron spin structure functions from the measurements. More recently, Peter Sauer succeeded in his long-time goal of investigating the effects of the Δ isobar excitation in few-nucleon scattering. This was achieved by very complex calculations of nd elastic scattering, breakup reactions, nd radiative capture, and electrodisintegration of the three-nucleon bound state.

Last, but not the least, we refer to Peter Sauer's work on three-nucleon forces and their relation to the role of the Δ-resonance in the nuclear medium, as well as the role of pionic degrees of freedom. He and his group pioneered the investigation of three-nucleon forces of shorter range than $\pi - \pi$ exchange, emphasizing the importance of consistency in the modeling of those forces.

Peter Sauer as a Teacher
Three of the organizers of the workshop belong to the large group of people who, while working with him as postdocs, were exposed to his "Socratic" attitudes, as Dan-Olof Riska at the conference banquet put it. In the final speech at the conference dinner, Franz Gross revealed how impressed he was in the early 80's (before the "powerpoint age") by the scarce number of words in Peter's transparencies for conference talks, and how invariably they were organized in the form of questions. In discussions, Peter Sauer strongly believes in the power of simple and unexpected questions, together with demanding consistency, in probing methods and results. His pedagogical qualities were testified in the meeting, in a marvelous and touching way, by his former students Uwe Oelfke and Ralf Schultze-Riegert. Among other memories, they recalled how thoroughly organized and still appropriate for today's use Peter's notes were, which today exist (unpublished in stacks on Peter's shelves) on a large variety of subjects in Theoretical Physics.

The legacy is out there... To testify it, we included in this volume the three talks presented in the closing session, which was dedicated to tributes to Peter Sauer. As such, they were not restricted to nuclear dynamics at intermediate energies. However, these talks highlighted how a training in Nuclear Physics of high standards, such as the training one could benefit from while working with Peter Sauer, is conducive to very diverse professional choices, within physics and also outside it. Moreover, even though Peter Sauer's work may have affected only a small segment of society, we came out from the closing session with a strengthened certainty: due to the diversified links of Nuclear Physics to Astrophysics, Biomedicine, Industry and Energy Production, Computing and Simulation, it can no longer continue to be inevitable that "the nuclear community tends to be too insular", as commented by the EU Commissioner for Research, Philippe Busquin, in one of his interviews. Still quoting the same Commissioner, "...nuclear scientists have had a tremendous impact on scientific advances in other fields that have benefited society ...". It is time to make our patrimony more widely known.

Lisbon, February 2003
The Editors

Acknowledgement. The editors want to express their appreciation to the conference secretariat, Sandra Oliveira and Dulce Conceição, for their professionalism and the smooth way they solved many problems. We thank also all the administrative staff of IST and CFNUL, involved in the preparation of the workshop or these proceedings.

Contents

Electroweak Probes (I)

The Nuclear Interaction and Meson Production From Light Nuclei

Electroweak Probes (II)

The Nuclear Medium Under Extreme Conditions

Constituent Quark Models and Chiral Symmetry

Relativity and Electromagnetic Observables

Non-Nucleonic Degrees of Freedom

Relativity, Chiral Symmetry, and Form Factors of Baryons and Mesons

Nuclear Structure and Binding

Tributes to Peter Sauer

Few-Body Systems Suppl. 15, 267–270 (2003)

Few-
Body
Systems

From $\gamma - d$ to $\gamma -$Tumor: Peter Sauer's Influence as a Teacher

U. Oelfke *

Department of Medical Physics, Deutsches Krebsforschungszentrum (DKFZ), DKFZ, E0401, Im Neuenheimer Feld 280, 69120 Heidelberg, Germany

Abstract. As indicated by its title this short contribution to a rigorous physics journal does not contain any genuine scientific contribution. It's main purpose is to honor one of the most respected members of the "Few Body Systems" community - Peter Ulrich Sauer (PUS) - for his life long commitment to educate students.

1 Introduction

Although being a student of PUS a long time ago, i.e., for almost 10 years from the early 1980's to 1990 when leaving from Hannover to TRIUMF, it was not difficult at all to recall his enormous influence he had on his students. I appreciate the opportunity given to me by my old friends – Teresa Penã, Jiří Adam and Alfred Stadler – to present my respective experience with PUS at their excellently organized workshop in Lisbon.

The aim of this note is two-fold. First, to show that a profound education in theoretical nuclear physics can be applied also to more practical areas of life, e.g., the development of more efficient cancer therapies through the clinical application of high energy photon, proton and heavy ion beams. Second, to emphasize and remember the role of PUS as a teacher, whose personal commitment to his students, in my opinion, was crucial for their success in their professional careers.

---

[*] *E-mail address:* u.oelfke@dkfz-heidelberg.de

2 Material and Methods

2.1 Nuclear Physics and its Application in Radiation Therapy

About ten to twelve years ago nuclear physics of few-body systems was mostly related to the canonical topics, i.e., form-factors, relativistic effects and wave functions, polarization observables, quark- or nucleonic degrees of freedom etc.. According to my impression from the scientific part of the workshop no revolutionary discovery has been made since; slightly new phenomena were discussed in a similar context and analyzed with comparable intellectual rigor. In the following I will shortly describe a different, more applied area of physics, whose direct benefit to society is immediately evident: the application of nuclear physics techniques to tumor therapy.

Proton Therapy of Inner-Ocular Tumors
Over the world, roughly 10 proton accelerators, originally built for basic research in nuclear physics – mostly cyclotrons with maximum proton energies between 60 and 70 MeV — were adapted for the treatment of inner-ocular tumors. Protons at these energies with a maximum range of 3 - 4 cm in water, can be delivered with a spatial accuracy and precision of less than a millimeter into tumor tissues, while other radio-sensitive structures of the eye, e.g., the optic nerve, can be highly spared from being irradiated. Almost 10.000 patients have had this extremely successful therapy, e.g., the achieved local tumor control rate ranges between 96% and 98%. Especially for 'Uveal Melanomas' this tumor therapy, pioneered at the Harvard Cyclotron in Boston and at the Paul Scherrer Institute in Villigen, has saved a considerable number of lives of cancer patients.

Intensity Modulated Radiation Therapy with High Energy Photons
The technique of modern linear accelerators applied in standard radiation therapy are based on the development of electron accelerators, applied for nuclear physics research. Furthermore, recent developments, have lead to a new form of radiation therapy, called 'intensity modulated radiation therapy'(IMRT). The idea is to divide a radiation beam into hundreds to thousands of small radiation sources, whose contribution to the overall tumor dose can be controlled independently. The construction of the respective dose delivery devices, so called electronically driven multi-leaf collimators, and the development of new therapy optimization methods ('inverse planning') was initiated by physicists. The IMRT concept allows the treatment of tumors which are in very close proximity to organs at risk with very high doses, e.g., it is expected that the clinical results for the irradiation of tumors adjacent to radio-sensitive tissues will substantially improve through the introduction of IMRT.

Intensity Modulated Proton and Heavy Ion Beams
The most advanced radiation therapy technology in the battle against cancer, again, originates from nuclear physics laboratories. The concept of intensity

modulated charged particle therapy (IMPT) utilizes high energy proton and heavy ion beams, which are magnetically scanned over the considered tumor volumes. In addition to the lateral position of the beam spots and the particle fluence one can also control the particle energy, which determines the penetration depth of these particles in tissue. Research on heavy ion therapy was initiated already in the 1950's in Berkeley and was perfected to its modern form, e.g., by pilot projects at research labs like the Harvard Cyclotron, PSI (Switzerland) or GSI (Germany). Several clinical centers were recently opened or are planned in the US, Japan and Europe. The potential of this new therapy form originates from it's significantly improved dose conformity around the tumor volume, e.g., for prostate tumors radiation induced complications in rectum and bladder can be reduced considerably.

2.2 Education by a "Center of Excellence": P. U. Sauer

The conversion from theoretical physics into quite a different field – an area where the knowledge of basic science is merged with medical experience – is naturally accompanied by a phase of learning completely new methods and strategies. The respective process requires a solid and profound education as a scientist, which is strongly correlated to the 'teacher' one is exposed to. In the following I briefly describe my personal experience with PUS as a teacher in order pay tribute to his efforts in guiding and helping students to become independent scientists.

Learning through Lectures and Visitors

The first outstanding fact about PUS' teaching are his lectures. They were always extremely well prepared, contained a very clear and concise presentation of the ideas which often were followed by well selected, explicit examples. Furthermore, PUS made the effort to teach all the required mathematical tools and foundations, so that students actually could 'do' calculations by themselves. Notes taken in classes taught by PUS could serve as reference of the respective topic for the rest of one's professional life.

The next cornerstone of PUS' education concept was that he provided opportunities for his students to interact with exceptional scientists from other institutions. While studying with PUS in the 80's we could enjoy long term visits and lectures from J. Koch, F. Coester, F. Gross, R. Rosenfelder, E. Truhlik, J. Adam, R. Mach, T. Peña, H. Garcilazo and S. N.Yang. The diversity of this group and the opportunity to observe and independently interact with these visitors provided his students with an invaluable experience for their future professional development.

Organizing Physics and Benevolent Support

Another specific education tool of PUS was his system of organizing lectures and projects in hand written notes, each labeled by a three letter abbreviation of the respective topic, e.g. PIP, $\gamma N\Delta$, RSS .... These treasures, well stacked in one (maybe more) of his metal cabinets, provided an extremely helpful source of information for many students and collaborators of his.

Besides PUS's qualities as a scientist and teacher of physics I also want to mention his fair judgement and personal support of his students. From my experience PUS spent significant time and energy on a fair evaluation of his student's accomplishments. Although never obviously close to his students PUS has always shown considerable patience and respect to those working with him.

Papers and Pain
Writing papers with PUS naturally led to different stages of pain for his collaborators, mostly related to N+1 versions of a manuscript ($N \geq 8$), whose flood of 'red' comments on its margins simply never vanished ... However, we have to admit his quest for the highest standards in a publication, often paid off and at the end, there was a beneficial educational component for us too...

3 Conclusions

At present there are evolving exciting new applications of nuclear physics in medicine, e.g., the briefly sketched developments in radiation therapy. The ability to work as a scientist in basic physics research or one of these more applied professional areas requires a solid education mediated by teachers. The workshop in Lisbon provided us with the opportunity to honor PUS not only for his scientific achievements but also for his outstanding efforts in educating his students. His generous sharing of ideas, his excellent lectures, his personal support and his conduct as a scientist inspired us and was therefore crucial for the successful development of our professional lives.

Few-Body Systems Suppl. 15, 271–272 (2003)

Few-Body Systems

From Physics to Consulting

Ralf Schulze-Riegert*

Scandpower GmbH, Weidestr. 126, 22083 Hamburg, Germany

After almost a decade out of physics it was a pleasure to join this year's Fall Workshop on Nuclear Dynamics in Lisbon. The fact that the organisers have dedicated the workshop to my former teacher and supervisor Peter Sauer has made it a special event for myself. For one thing, this event gave me an opportunity to reflect on the status of research of few-nucleon systems I was actively involved in. For another, the organisers have prepared a pleasant atmosphere to meet and to talk to many of my former colleagues and collaborators.

Ways into and out of physics was not a major topic of this conference, but has still created some interest. For many graduate students in physics, a position in a research institution has an appealing perspective. A liberal environment and work dedicated to technical and intellectually demanding problems with few constraints along with publishing papers. However, perspectives in physics and nuclear physics in particular have changed with periodic ups and downs. Questions on future perspectives and working opportunities are therefore not just a matter of a particular time but keep recurring.

The consulting business has gained a major role in our world which requires a multitude of specialized services. It has grown significantly, contributing to economic growth in the nineties and still absorbs numerous graduate students. The consulting business for physicists is diverse, starting from the IT business, Research-and-Development consulting (which merges research and industry needs), business process consulting, financial risk management consulting up to scientific advisory board level, which creates a link to politics. Physicists are active in all of these fields, and the opportunities are as diverse as the term Consultant is used for different services. Outside of physics, graduates with a degree in physics are competing with other qualifications under continuously changing market requirements. Nevertheless, a technical and mathematical background has proven to be a valuable foundation. Consulting services in

---

* *E-mail address:* riegert@scandpower.de

industry require technical insights, the ability to share knowledge and social competence.

Working with Peter Sauer has combined these requirements. Graduate level work was often embedded in an international environment inasmuch as Peter Sauer worked together with his students and external collaborators to write scientific papers. Personally, I particularly wish to mention our collaborations with Tobias Frederico (ITA, Brazil) and Fritz Coester (Argonne, USA). These collaborations triggered many controversial as well as productive discussions in our group in Hannover, of which I have found memories. However, our goal to formulate physics problems was also very much linked to experiments, such as the calculations we performed in collaboration with MIT-Bates and others. I regard this as a valuable feature of few-nucleon physics, which defines a close link between theoretical and experimental physics.

Peter Sauer liked to travel but did not hesitate to send his students abroad to work and to present their work at conferences. In his summary to the Heisenberg Conference in 1991, C.D. v. Weizsäcker concluded, "physics conferences are partly organised to chat, perhaps with an interest to support one's career. But truly, they are also organised because we appreciate talking about things which we hope – if we continue to work on them for a few more decades – will allow us to make a really big step forward". Today, decades as a time frame for our work are out of sight, and we accept that big steps are rare and largely driven by efforts to put together pieces of a larger puzzle. This work can be organised with all the discipline and creativity it requires. Peter Sauer as a researcher and lecturer – or in business terms, as an auditor and research manager – concentrated a great deal on advising students and organising a culture of international collaborations. This created both challenges and opportunities to his students. In retrospect, it was a most valuable preparation for working both in research and industry.

Few-Body Systems Suppl. 15, 273–281 (2003)

Few-Body Systems

Celebrating Peter Sauer: an Occasion to Look at Nuclear Physics in Perspective

B. Frois*

Ministère de la Recherche, 1 rue Descartes, 75231 Paris, France

Abstract. This talk was presented at the symposium organized by Peter Sauer's friends in Lisbon. This symposium was a wonderful occasion to celebrate the importance of his achievements and examine the trends and perspectives in nuclear physics in 2003.

1 A Tribute to Peter Sauer

I would like first to give my warmest thanks to the organizers of this meeting celebrating Peter Sauer and his achievements. This is a very thoughtful initiative of his friends in Lisbon. I am very pleased to be able to share this precious moment with Peter Sauer and his friends.

Peter Sauer and his group have written an important page of the history of few-body physics. I would like to mention in particular their contribution to the understanding of the three-nucleon system. At the beginning of the 70's, the mathematical tools to solve the three-body systems were known, but calculations were showing some striking disagreements between experiments and theory. A discrepancy of 1 MeV was observed in the difference between the ^{3}H and ^{3}He binding energies. The charge distribution of ^{3}He observed by electron scattering seemed to have a hole at the center of the nucleus that no calculation could explain. One was beginning to believe that the role of non-nucleonic degrees of freedom such as π's and Δ's was not sufficiently well understood. There was a great need for consistent and reliable calculations of few nucleon sytems with realistic potentials.

Although nucleon-nucleon interactions are traditionally described in terms of meson-exchange processes, non-nucleonic degrees of freedom are omitted from calculations and nuclei are described as "dressed" nucleons interacting via a two-body potential. The first convincing observation of non nucleonic degrees of freedom was the precise measurement of the magnetization distribution

---

[*] *E-mail address:*bernard.frois@recherche.gouv.fr

involved in the electrodisintegration of the deuteron in 1985 at Saclay. When the energy transferred to the deuteron by the incoming electron corresponds to its break-up energy (2.2 MeV), the neutron-proton pair has a very small relative energy $E \simeq 0$. If, in addition, the electron is scattered at an angle $\theta \simeq 180°$, the electrodisintegration of the deuteron is a magnetic isovector M1 transition that leaves the two-nucleon system in a quasi-bound ${}^1S_0$ (T = 1) state. Theoretical calculations of electron scattering which take into account only nucleon degrees of freedom predict a minimum at $Q^2 = 0.5\ (\mathrm{GeV/c})^2$; this is not observed experimentally. The filling of this minimum to higher Q^2 values is due entirely to the presence of meson-exchange currents (Fig. 1). Present calculations which include both nucleonic and mesonic degrees of freedom provide an excellent description of the data up to $Q^2 = 1\ (\mathrm{GeV/c})^2$.

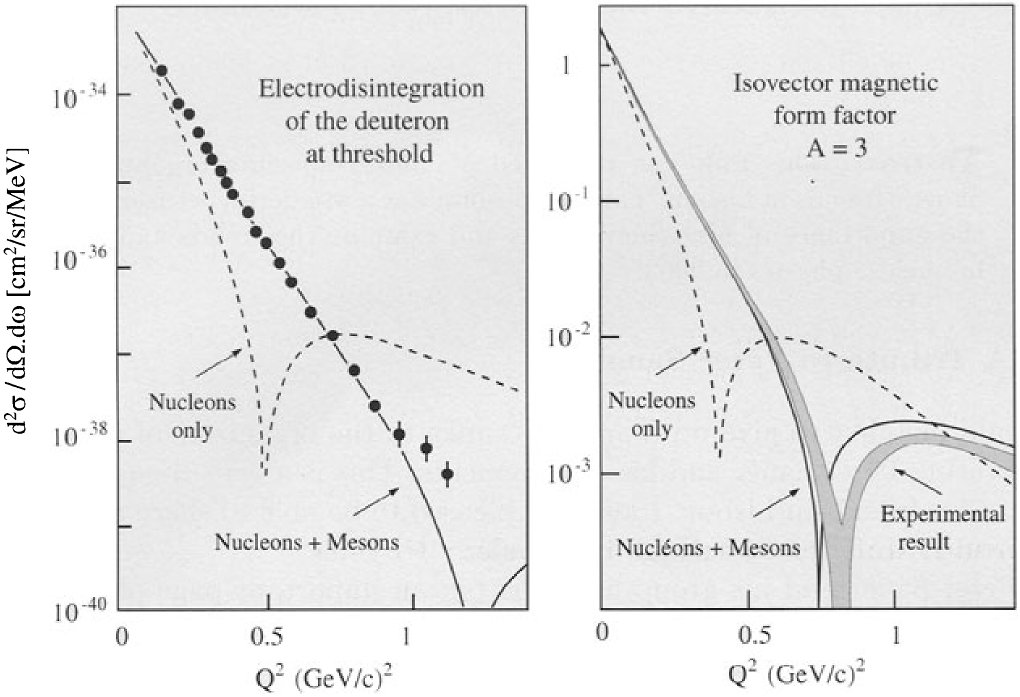

Figure 1. Comparison of the isovector magnetic form factors of the $A = 2$ and $A = 3$ systems.

The confirmation of the importance of non-nucleonic degrees of freedom came a few years later with the comparison between the measurements of the ^{3}He and ^{3}H charge and magnetic form factors and calculations performed by Peter Sauer and his group. They were the first to develop a new generation of consistent calculations for the $A = 3$ nuclei in terms of nucleons, pions and isobars based on a realistic potential. Their calculations also take into account a significant component of the three-body force. This work was a tremendous help to prepare and interpret the measurements of the form-factors of the ^{3}H and ^{3}H at Saclay. Tritium is radioactive nucleus. Building a tritium liquid target was a "tour de force" at Saclay that lead to very precise results and triggered considerable interest. The trinucleon charge and magnetic form factors were determined up to 1 $(\mathrm{GeV/c})^2$ by elastic electron scattering. These data allowed one to separate their isospin components up to this momentum transfer value. Thus a direct comparison of the isovector magnetic form factors of the two- and three-nucleon systems became possible. In particular, the isovector magnetic form factor can be compared with the cross section for the electrodisintegration of the deuteron at threshold.

Fig. 1 show that the isovector transitions in two- and three-nucleon systems has essentially the same behavior. The nucleonic contribution to the cross section vanishes at a relatively small momentum transfer due to the destructive interference between one-body amplitudes. When the same two-body currents that explain the isovector magnetic form factor for the electrodisintegration of the deuteron, are included in the theoretical description of the three-nucleon system, there is an excellent agreement between experiment and theory. Again, pion-exchange currents are the dominant contribution to the cross section up to $Q^2 \simeq 0.6$ $(\mathrm{GeV/c})^2$.

Thanks to Peter Sauer and his group, major theoretical progress has been achieved in the understanding of the three- and four-nucleon systems. We believe that the ground state wave function of the three-nucleon sytem is now well understood. Considerable progress was also achieved by Vijay Pandharipande and his group in Urbana, using Monte-Carlo techniques; they have shown that variational methods confirm these results and allow one to extend these calculations to the $A = 4$ system and heavier nuclei. The binding energy of the triton, the charge distributions and the charge radii of ^{3}He and ^{3}H are now well described by theory.

2 Trends and Perspectives in Nuclear Physics

2.1 Hadrons and Nuclei

At the end of the 80's, building a 4 GeV continuous and intense beam electron facility became the focus of discussion in Europe and in the United States. Unfortunately, endless discussions in Europe did not lead anywhere while in the United States a well organized community decided the construction of such a machine at Newport News, in Virginia. This machine (CEBAF) is today one of the major US facility in nuclear physics. CEBAF has now become Jefferson Lab, the Thomas Jefferson National Accelerator Facility. It is the flagship of a highly active community; in its recent long range plan, NSAC has recommended an evolutionary upgrade of Jefferson Lab to 12 GeV, as a priority of the US scientific community.

The most impressive success of CEBAF is the availability of three simultaneous 6 GeV electron beams with both high intensity and high polarization (70%) that are now routinely available. Advances in techniques using polarized electrons has yielded a wealth of data on the nucleon form factors, achieving an unprecedented level of precision. Until recently, the charge and magnetization distributions in the proton were assumed to be proportional to one another (corresponding to $\mu G_e/G_m{=}1$). New data show that this is not true, and is leading to a re-examination of the dynamics governing the proton's quark wavefunctions. An extensive research program on the electromagnetic structure of the proton and neutron form factors using polarization techniques is in progress.

Strange quark-antiquark pairs are constantly bubbling up in the proton. One would expect a substantial probability of strange quarks and a corresponding contribution to the charge and magnetization distributions of the proton. To disentangle this contribution from the dominant effects of the u and d quarks requires the use of the weak interaction (Z exchange) as a probe of the strange proton form factor. The HAPPEX experiment has shown that the actual contribution is considerably smaller than expected in most models.

After many years Japan has decided to build a major 50 GeV and 1 MW multipurpose proton facility. Several beams, including intense kaon beams, will be available for particle and nuclear physics. This should allow the study of strange hypernuclei to be pushed into new regions. Intense neutrino beams directed towards the Super-Kamiokande detector will allow one to study new features of neutrino oscillation. Finally, neutron physics and transmutation of nuclear wastes will be also important parts of the research program.

A major development is the considerable progress in lattice QCD that has been made recently and which is promised for the next few years. Developments in improved quark and gluon actions have increased to lattice spacing that one can use while still obtaining accurate continuum results. Funding agencies in Europe and the USA have agreed to support a number of dedicated High Performance Computers, all at the level of 10 Teraflops or thereabouts. These machines should permit full QCD simulations at quark masses only a factor of 3 or 4 above the physical light quark masses. The combination of improved chiral extrapolation and the new generation of supercomputers means that we can look to lattice QCD producing accurate hadron properties at the physical quark masses within the next five years.

2.2 The Limits of Nuclear Stability

One of the questions of current interest is whether or not the role of the magic numbers, well established along the valley of stability, remains important when an extreme excess of protons or neutrons is present in a nucleus.

The doubly-magic nucleus ^{48}Ni was recently observed for the first time at the National Heavy Ion Facility (GANIL) in France using a high-intensity ^{58}Ni beam at 74.5 MeV/A on a nickel target. It is the only case of a doubly-magic nucleus for which the mirror nucleus, ^{48}Ca, is bound. A lower limit of its half-life of about 0.5 μs and an estimate of the production cross-section around 0.05 pb were deduced.

In the domain of super-heavy element research, the discovery of the element 112 at GSI is confirmed while the existence of elements 114 and 118 remains a question.

Another important experimental result has permitted to confirm the existence of a decay mode that has been actively sought for 40 years by the nuclear physics community. In two very recent experiments, one at GANIL in France and one at GSI in Germany, an international team of physicists has demonstrated that the ground state of the atomic nucleus Iron-45 decays directly by the emission of two protons. For the first time, the results from the experiments at GSI and at GANIL demonstrate that a nucleus with very large proton excess can spontaneously disintegrate by double proton emission from its ground state with a comparatively long half-life, which can therefore be directly measured. This should allow one to study the mechanism of two-proton emission, thus opening up a new way for observing the internal forces governing the atomic nucleus.

2.3 Rare Isotope Beams

First generation Radioactive Nuclear Beam (RNB) facilities are operating or under construction in the three regions of the world where nuclear physics is most actively pursued, Europe, North America and Asia/Pacific. These facilities continue to produce important results, and ambitious experiments are planned with them in the next few years. However, several studies of the projected needs of nuclear physics carried out all around the world have made it quite clear that major breakthroughs towards the ultimate scientific goals will only be achieved by the next generation of RNB facilities.

The GSI laboratory in Germany has presented to the scientific community the conceptual design report of a powerful new accelerator facility generating intense high quality secondary beams, including radioactive nuclei and antiprotons. The new facility will provide beam energies of a factor 15 higher than presently available at GSI for all ions, for protons to uranium. Compared to the present GSI facility, the primary beam intensity will be a factor of 100 higher and a factor 10,000 in secondary radioactive beam intensities. The research program will be focused on the investigation of nuclei far from stability, dense hadronic matter and many-body nuclear physics.

2.4 Matter at Extreme Pressures and Temperatures

The quark gluon plasma is a state of matter that is predicted to have existed some 10 microseconds after the occurrence of the Big Bang. Seven different experiments at CERN, in which 33 TeV lead ions crashed into heavy element targets give strong hints of the existence of the quark gluon plasma. But confirmation of the existence of this new phase of matter awaits a new generation of results from the Relativistic-Heavy-Ion-Collider (RHIC) at Brookhaven and the future Large Hadron Collider at CERN. RHIC has now attained full energy with 100 GeV gold ions colliding with 100 GeV gold ions. The first experimental results were presented at INPC 2001 in Berkeley.

Beginning in 2007, part of the experimental program of the CERN Large Hadron Collider (LHC) will be devoted to the study of nuclear collisions in the special-purpose ALICE detector, at energies some thirty times higher than RHIC.

2.5 Nuclear Astrophysics

The origin of the universe is one of the most exciting question in physics. A new understanding of the history of our universe has emerged with the many discoveries that led to the theory of the Big Bang. The very light elements were created in the Big Bang and then the remaining elements arose from the processes involved in the birth, life and death of stars. Cosmology uses important inputs from nuclear physics. Many fundamental questions in the future will be addressed with nuclear astrophysics experiments.

Some of the most exciting results are the recent observations from the Sudbury Neutrino Observatory (SNO) in Canada. This laboratory, funded for a large part by the nuclear physics community, uses a considerable amount of heavy water to interact with cosmic neutrinos. The results have solved the mystery of the missing solar neutrinos, a puzzle for solar theory for more than 30 years. The results confirm that solar models are correct but give evidence that neutrinos decay and oscillate in their journey to the earth. Neutrinos transform from electron-neutrinos to muon- and/or tau-neutrinos. The flux of electron-neutrinos, measured in the charge current interaction $\nu_e + d \to p + p + e^-$, together with earlier results from Super-Kamiokande on the neutrino elastic scattering flux (encompassing all three neutrino types) $\nu_x + e^- \to \nu_x + e^-$ show that there is a non-electron type, active neutrino component in the solar flux. The total flux of active ^{8}B neutrinos that can be so deduced is in excellent agreement with the predictions of solar models.

3 Important Applications of Nuclear Physics

3.1 Cancer Therapy with Nuclear Beams

The goal of radiation therapy is to maximize the tumor dose without harming surrounding healthy tissues. The use of heavy particles in radiotherapy is motivated by a superior accuracy in the spatial dose distribution in the human body for deep seated tumors compared to photons and electrons, and an inverse dose profile depositing the highest dose at the end of the particle range in the tumor volume.

For proton therapy, the needed accelerators are, at present, industrial products, while optimized medical synchrotrons for light ion therapy have recently been designed by CERN and GSI. Active beam delivery systems using magnetic beam deflection and energy variation by the accelerator have recently been developed, and have been put into operation at PSI (Switzerland) for protons, and at GSI (Germany) for carbon beams.

Using positron emission tomography (PET), the small amounts of positron-emitting isotopes created by the carbon beam can be used to determine the exact beam location inside the patient's body. The new techniques of more accurate beam delivery and precise control permit the treatment of tumors in critical locations such as the brain, or the vicinity of the spinal cord.

3.2 Nuclear Energy Research

Fossil fuels, coal, oil and gas, currently meet more than 85% of world energy needs and will continue to dominate for some time. There is no longer any doubt that the increase in atmospheric CO_2 is due to our growing use of these fuels without any containment of the CO_2 waste. The latest report of the Intergovernmental Panel on Climate Change (IPCC) predicts that the effect of a continuation of this increase in CO_2 on the earth's climate will be significant and often damaging, with rising sea levels, more storms, floods and droughts, the destruction of precious habitats.

Large quantities of additional energy will be needed to fuel economic growth, especially in developing countries with large populations like China, India and Brazil. Currently, some two billion people have no access whatsoever to commercial energy; many more are quite poor by western standards and all will need more energy in the future. If recent trends in energy use continue, as most economic analysts expect, then worldwide demand will grow by about 50% by 2020 and will double by 2050. The growth will be even larger for electricity since, more than any other form of energy, electricity is an essential ingredient of economic development. Yet this growth with the present mix of fuels can only lead to more ecological problems.

Providing more energy economically while limiting the use of fossil fuels is difficult. There is no simple solution. All available options must be considered with an open mind. The world as a whole, therefore, needs to develop carbon-free energy sources.

The new 'renewable' sources of energy, solar power, wind power, biomass etc., are also carbon free and there is a widespread hope that they will supply higher and higher percentages of our energy mix, but it will not happen easily. This is not because of insufficient R&D. Solar photovoltaics, for instance, have benefited from large R&D investments because of their usefulness in space applications. Similarly, tens of thousands of wind generators have been built worldwide. The problem is the cost of the energy and resistance to deploying these low intensity sources, which inevitably impact significantly on the local environment. In 1980, 10% of the Swedish electricity in the year 2000 was foreseen to come from wind power. The correct number in 2000 was 3%.

Hydropower is cost effective, but potential sites are limited and often precious for other reasons so that its growth is also constrained. The OECD expects its contribution to primary energy to fall from 3% today to 2% by 2020. Renewable energies will not, at least for the foreseeable future, provide for the increased energy need

Nuclear fission is one of the few large-scale carbon-free energy sources and currently provides 7% of global primary energy (17% of electricity) without any CO_2 waste. Its costs are now well known and are unaffected by increases in oil and gas prices. It supplies 35% of the electricity generated in Europe, i.e., 75% of its CO_2free power.

Nuclear power does produce radioactive wastes. However, the shortlived wastes from operations are already disposed of safely in many countries. Comprehensive research for decades has led to a common view among international experts that the *"knowledge and technology exist"* for safe waste management, ready to be used by society. The final disposal of the longlived waste is not yet industrially implemented, but demonstrations are under way in several countries.

Today, overall, only 4% of the initial quantity of fuel is consumed in a reactor, i.e., less than 1% of the quantity of natural uranium needed for the production of enriched uranium. The spent fuels removed from the reactors contain 95% of uranium, 1% of plutonium and 4% of fission products. *Only fission products constitute waste. Uranium and plutonium can be re-used to produce energy.* With the dual aim of economizing natural resources and optimizing waste management, some countries, such as France, process the spent fuel to separate the energy-yielding materials from the waste. The recycled uranium is stored with the prospect of its use at a later date in fast breeder reactors, and the plutonium is recycled in today's reactors in the form of MOX fuel, a mix of uranium and plutonium. If the use of nuclear energy is to be greatly expanded to reduce man-made greenhouse gases, some such system will be needed.

To continue the development of nuclear energy, we must provide effective and acceptable technical solutions for the long-term management of the radioactive wastes produced by current reactors; solutions do exist and could be gradually implemented. Studies are underway on multiple recycling of plutonium in power reactors, thus destroying it and leaving the fission fragments and minor actinides for geological storage. Also under study are transmutation systems which convert the long-lived component of spent fuel to a form only requiring isolation for on the order of hundreds of years to a thousand years – a time span of already existing man-made structures.

Preparation for the future sustainable development of nuclear energy will involve a new generation of nuclear power generation systems, in an inclusive approach covering all the aspects of the reactor and fuel cycle. The "Generation IV" international initiative (Europe, United States, Japan, Russia, etc.), aims to develop, for deployment around 2030, new types of nuclear reactors which are simpler, completely free from coremeltdown, and competitive with the best fossilfired plants, as well as fuel cycles more resistant to proliferation. Comprehensive assessment studies have already demonstrated that these objectives are achievable.

Globally, the processing of spent fuels, the consumption of the plutonium in light water reactors, and the transmutation of long-life radiotoxic wastes (minor actinides) in the new generation reactors, could reduce the long-life radiotoxicity of the waste by a factor of 100, leaving a residual radioactivity that would then be comparable to that of the initial natural uranium after several hundred years.

Innovative nuclear energy research is of paramount importance to develop improved designs, maintain and renew expertise, whilst continuing to build competence in operation and decommissioning of the present generation of reactors.

4 Thermonuclear Fusion

Nuclear fusion has made significant progress in the last ten years. In 2002 Europe, Japan and Russia have decided to build ITER (International Thermonuclear Experimental Reactor), which will be the largest scientific facility built worldwide. ITER is a superconducting Tokamak that will be the next step, following the Joint European Torus (JET) facility in operation in England.

The ITER project has its origins in the world wide recognition that: fusion is a long-term energy source, with acceptable environmental characteristics. The goal of this new facility is to allow, in one device, full exploration of the physics issues as well as proof of principle, testing of key technological features of possible fusion power stations and demonstration of their safety and environmental characteristics. It is an international collaborative framework which allows participants to share costs and pool scientific and technological expertise towards a common goal.

Nine years of intensive joint work by the ITER teams under the auspices of the IAEA have yielded a mature design supported by a body of validating physics and technology R&D, safety and environmental analyses and industrial costing studies. After Conceptual Design Activities between 1988-1990, the Engineering Design Activities began in 1992 and are now completed with the ITER design. Following the choice of site and the commitment by the ITER parties of suitable funds, the construction phase (about 10 years) may start. This would be followed by an exploitation phase lasting roughly 20 years.

The United States and China have decided to join the ITER project together with Europe, Japan and Russia. Four sites have been proposed to host ITER, in Canada, France, Spain and Japan. The choice between these propositions is expected to take place in 2003. ITER will provide the integration step necessary to establish scientific and technical feasibility of fusion as an energy source.

5 Conclusions

The work of Peter Sauer and his group was a major step in our understanding of few-nucleon systems. It definitely established the presence of meson-exchange currents by the comparison between the electrodisintegration of the deuteron and the isovector $A = 3$ magnetic form factor. This was a fascinating period where experiments and theory interacted strongly. In a few years electron scattering data produced considerable advances in nuclear physics. I really enjoyed this period.

The frontiers of nuclear physics are continuously moving to new domains. Nuclear astrophysics, the study of hadrons and hadronic matter, new radioactive beam facilities will explore new limits. Society also expects more concern from scientists. Nuclear applications in particular concerning nuclear wastes, nuclear energy and cancer therapy are topics of increasing importance. Nuclear Physics has a bright future.

LIST OF PARTICIPANTS

Jiří Adam
Dept. of Theoretical Physics
Nuclear Physics Institute
250 68 Řež near Prague
Czech Republic
`adam@ujf.cas.cz`

Ana Arriaga
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`arriaga@cii.fc.ul.pt`

Zoltan Batiz
CFIF/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
`zoltan@cfif.ist.utl.pt`

Gordon Baym
Department of Physics
University of Illinois
at Urbana-Champaign
1110 West Green Street
Urbana, IL 61801-3080
USA
`gbaym@uiuc.edu`

Nicola Bianchi
INFN
Laboratori Nazionali di Frascati
Via E. Fermi 40
I-00044 Frascati
Italy
`bianchi@hermes.desy.de`

Jean-Christophe Caillon
Centre d'Etudes Nucléaires
Univ. Bordeaux I
IN2P3 Le Haut Vigneau
33175 Gradignan Cedex
France
`caillon@cenbg.in2p3.fr`

Juan Antonio Caballero
Dept. de Física Atómica,
Molecular y Nuclear
Universidad de Sevilla
E-41080 Sevilla
Spain
`juan@nucle.us.es`

Sidney A. Coon
D.O.E., Div. of Nuclear Physics
SC-23/Germantown Building
1000 Independence Avenue, SW
Washington, D.C. 20585-1290
USA
`Sidney.A.Coon@science.doe.gov`

Fritz Coester
Argonne National Laboratory
Physics Division
Argonne IL 60439
USA
`coester@theory.phy.anl.gov`

Arnoldas Deltuva
Institut für Theoretische Physik
Universität Hannover
Appelstrasse 2
30167 Hannover
Germany
`deltuva@itp.uni-hannover.de`

Jorge Dias de Deus
CENTRA/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
`jdd@fisica.ist.utl.pt`

Ana Eiró
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`ana.eiro@fc.ul.pt`

J.O. Fiase
Department of Physics
University of Botswana
P.B. 0022, Gaborone
Botswana
`fiasejo@mopipi.ub.bw`

Manuel Fiolhais
Departamento de Física
Universidade de Coimbra
3004-516 Coimbra
Portugal
`tmanuel@teor.fis.uc.pt`

Antonio C. Fonseca
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`fonseca@cii.fc.ul.pt`

Tobias Frederico
Departamento de Física
Instituto Tecnológico de Aeronáutica
12.228-900, São José dos Campos
São Paulo
Brazil
`tobias@fis.ita.br`

Bernard Frois
Directeur du DTA4
Ministère de la Recherche
1 rue Descartes
F-75231 Paris cedex 05
France
`bernard.frois@technologie.gouv.fr`

Humberto Garcilazo
Instituto Politécnico Nacional
Escuela Sup. de Física y Matemática
07738 México D.F.
Mexico
`humberto@esfm.ipn.mx`

Franz Gross
Jefferson Laboratory, Theory Group
12000 Jefferson Avenue
Newport News, VA 23606
USA
`gross@jlab.gov`

Johann Haidenbauer
Forschungszentrum Jülich GmbH
Leo-Brandt Strasse 1
52425 Jülich
Germany
`j.haidenbauer@fz-juelich.de`

Brigitte Hiller
Centro de Física Teórica
Departamento de Física
Universidade de Coimbra
3004-516 Coimbra
Portugal
brigitte@teor.fis.uc.pt

William Jacobs
Indiana University Cyclotron Facility
2401 Milo B. Sampson Lane
Bloomington, IN 47408-1368
USA
jacobs@iucf.indiana.edu

Frieder Kleefeld
CFIF/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
kleefeld@cfif.ist.utl.pt

Jean-Marc Laget
Service de Physique Nucléaire
Centre d'Etudes de Saclay
91191 Gif-sur-Yvette Cedex
France
jlaget@cea.fr

Andrea Lavagno
Politecnico di Torino
Dipartimento di Fisica
C.so Duca degli Abruzzi 24
I-10129, Torino
Italy
alavagno@polito.it

T.-S. H. Lee
Argonne National Laboratory
Physics Division
Argonne IL 60439
USA
lee@theory.phy.anl.gov

Verónica Malafaia
CFIF/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
malafaia@cfif.ist.utl.pt

Laura Elisa Marcucci
Dept. di Fisica
Università di Pisa
Via Buonarroti,2 56127 Pisa
Italy
marcucci@df.unipi.it

Gerald A. Miller
Department of Physics
University of Washington
Seattle, WA 98195-1560
USA
miller@phys.washington.edu

Alexei Nefediev
CFIF/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
nefediev@cfif.ist.utl.pt

Filomena Nunes
Universidade Fernando Pessoa
Praça 9 de Abril
P-4200 Porto
Portugal
`filomena@wotan.ist.utl.pt`

Uwe Oelfke
Deutsches Krebsforschungszentrum
Im Neuenheimer Feld 280
D-69120 Heidelberg
Germany
`u.oelfke@dkfz.de`

Shinsho Oryu
Department of Physics
Tokyo University of Science
Noda, Chiba 278-8510
Japan
`oryu@ph.noda.tus.ac.jp`

Teresa Peña
CFIF/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
`teresa@cfif.ist.utl.pt`

Sérgio Pinto
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`sapinto@cii.fc.ul.pt`

Willibald Plessas
Institut für Theoretische Physik
Karl-Franzens Universität Graz
A-8010 Graz
Austria
`plessas@uni-graz.at`

Constança Providência
Centro de Física Teórica
Departamento de Física
Universidade de Coimbra
3004-516 Coimbra
Portugal
`constanca@teor.fis.uc.pt`

Gilberto Ramalho
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`Gilberto.Ramalho@cii.fc.ul.pt`

Dan-Olof Riska
Helsinki Institute of Physics
University of Helsinki
P.O. Box 64, 00014
Finland
`riska@pcu.helsinki.fi`

Bidyut Roy
Forschungszentrum Jülich GmbH
Leo-Brandt Strasse 1
52425 Jülich
Germany
`b.roy@fz-juelich.de`

George Rupp
CFIF/Instituto Superior Técnico
Av. Rovisco Pais
1049-001 Lisboa
Portugal
`george@ajax.ist.utl.pt`

Arunava Saha
Jefferson Laboratory
12000 Jefferson Avenue
Newport News, VA 23606
USA
`saha@jlab.org`

Filipe Duarte Santos
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`fdsantos@astro.oal.ul.pt`

Peter U. Sauer
Institut für Theoretische Physik
Universität Hannover
Appelstrasse 2
30167 Hannover
Germany
`sauer@itp.uni-hannover.de`

Nobuyuki Sawado
Department of Physics
Tokyo University of Science
Noda, Chiba 278-8510
Japan
`sawado@ph.noda.tus.ac.jp`

Rocco Schiavilla
Jefferson Laboratory, Theory Group
12000 Jefferson Avenue
Newport News, VA 23606
USA
`schiavil@jlab.org`

Yu. M. Shabelski
Petersburg Nuclear Physics Institute
Gatchina
188350 St. Petersburg
Russia
`shabelsk@thd.pnpi.spb.ru`

Ingo Sick
Institut für Physik
Universität Basel
CH-4056 Basel
Switzerland
`Ingo.Sick@unibas.ch`

Alfred Stadler
CFNUL/Universidade de Lisboa
Av. Prof. Gama Pinto, 2
1649-003 Lisboa
Portugal
`stadler@cii.fc.ul.pt`

Rob Timmermans
Theory Group
Kernfysisch Versneller Instituut
Zernikelaan 25 9747 AA Groningen
The Netherlands
`timmermans@kvi.nl`

John Tjon
Jefferson Laboratory, Theory Group
12000 Jefferson Avenue
Newport News, VA 23606
USA
`J.A.Tjon@phys.uu.nl`

Alfredo Valcarce
Grupo de Física Nuclear
Universidad de Salamanca
Plaza de la Merced
E-37008 Salamanca
Spain
`valcarce@mozart.usal.es`

Luping Yuan
Institut für Theoretische Physik
Universität Hannover
Appelstrasse 2
30167 Hannover
Germany
`Luping.Yuan@itp.uni-hannover.de`

AUTHOR INDEX