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FOM-evaluation

Programme FP31: Fundamental Interactions

results 1998-2002 and plans 2002-2006

(prepared by P.J. Mulders, programme leader)

Contents

1 Introduction

The objectives of the programme Fundamental Interactions were stated to be:

- Study of theoretical models incorporating the known electromagnetic, weak and strong interactions, aimed at predicting and describing new and existing experimental results.
- Development of mathematical and computational tools necessary for the analysis of such models.
- Understanding the conceptual basis of quantum field theory, in particular in connection with its symmetry properties.
- Study of the quantum mechanical description of gravity and the nature of space and time.

The programme was set up to focus on selected themes employing and also maintaining the existing diversity in expertise in the field of high-energy physics in the Netherlands. This would enable a swift response to new developments in theoretical high-energy physics. Three themes were selected, 'Phenomenology', 'Quantum field theory' and 'Quantum gravity and strings', although these are not strictly separable. Generally the research proposals were flexible and open to change. This is necessary as in theoretical physics progress cannot be enforced, developments are difficult to predict and directions change rapidly. Furthermore, parts of the research activities of the groups involved are carried out in other, e.g. international, co-operations such as EU or INTAS networks and the choice of research lines also depends on the feasibility of attracting postdocs and visitors. The programme FP31, however, contributes in a significant way to national collaboration and to the infrastructure of the theory groups at the university. The material budget in the programmes not only supports the graduate students and postdocs directly involved but also contributes to the possibilities for the staff to disseminate knowledge via conferences and workshops. It also allows the groups to invite short-term visitors that contribute to the success of the programme.

FP31 is a broad programme involving in phase I all university groups that perform research in the field of theoretical high-energy physics. At the start of the programme, the activities as far as postdocs and graduate students is concerned were roughly proportional to the size of the research staff involved. In phase I plans for 10 graduate student positions and 12 postdoc years were approved. Besides this, the programme included some material budget and financial support for 2 research staff positions resulting from earlier FOM commitments.

For phase II a similar number of graduate student positions and postdoc years has been foreseen. As a result of the dynamics in the field, a new FOM programme FP57 'String theory and quantum gravity' has recently been approved. This programme grew out of the research projects in this area within both FP31 (Fundamental Interactions) and the NIKHEF theory programme FP52 (Theoretical Subatomic Physics). The three theoretical high-energy physics programmes FP31, FP52 and FP57 constitute a national network of research groups in close contact with joint activities in the areas of research and education.

Relationship between the different programmes

The narrow ties between the various groups working on high-energy physics shows itself among others in the following:

- The organization of a series of national seminars (5 times per year) held at the NIKHEF institute, in which new developments are presented to the community. The morning talk usually features a visitor presenting new theoretical developments to the community of theoretical *and* experimental high-energy physicists, while in the afternoon the various projects of graduate student and postdoc are discussed by the theoretical community.
- In close co-operation with the national research schools for theoretical physics (DRSTP) and Subatomic Physics (SAF/NIKHEF), the network participates in the organization of academic training programmes in theoretical high-energy physics for PhD students in theoretical physics as well as in

experimental physics. These schools offer a balanced programme of lectures to Ph.D. students in their first and second year.

- The semi-annual meetings of the former FOM werkgemeenschap (facilitated by FOM), which included a representative of the NIKHEF group, in which scientific, organizational and financial issues were discussed. As of January 1, 2002 due to the restructuring of FOM the werkgemeenschap no longer exists as such. Instead, a 'Network Theoretical High-energy Physics' has been created run by the programme coordinators of the (presently three) relevant programmes FP31, FP52 and FP57.
- Staff members of various groups hold special professorships at other locations. J. Smit (UVA) has been appointed as an extraordinary professor in Utrecht (UU), J.W. van Holten (NIKHEF) is associated with the VUA in Amsterdam, J. Koch (NIKHEF) with the University of Amsterdam (UvA), E. Laenen (NIKHEF) with Utrecht (UU) and B. Schellekens (NIKHEF) with Nijmegen (KUN). These appointments stimulate collaborations between the various groups.
- Ph.D. students and post-docs at different locations work on joint projects and write joint publications. The beforementioned organization of schools and seminars at a national level also has led to a large mobility of graduate students, Ph.D. students and postdocs between the groups.
- Several workshops and conferences have been co-organized by different groups, e.g. a string conference in Utrecht, summer workshops on strings in Amsterdam and a workshop on QCD and deep inelastic scattering at the Lorentz center in Leiden.

2 Past performance (Phase I of FP31)

2.1 Introduction

As mentioned, in the original proposal three themes were selected, *Quantum field theory*, *Phenomenology* and *Quantum gravity and strings*, although these evidently cannot be strictly separated.

Quantum Field Theory

Quantum field theory (QFT) is the universal framework to describe nature at the atomic and subatomic level; as such it provides the basis of theoretical high-energy physics and a considerable part of astrophysics; it is also indispensable in the physics of condensed matter.

Work in QFT includes research on exact results and classical solutions, quantization, general aspects of perturbative methods, and non-perturbative and numerical studies. Exact results have been obtained in recent years for supersymmetric Yang-Mills theories by exploiting duality properties relating weak and strong coupling regimes. This can shed light on properties like confinement. In the non-supersymmetric context the analysis is much more difficult. Classical solutions, like solitons and instantons, are known to play an important role, and their study is an active field of research. Studies center around their properties and classification and the interplay with topology. Other aspects concern their role in the quantized theories, and the generalization to fields at finite temperature.

Apart from confinement, the analytical study of the dynamics of bound states in relativistic quantum field theory is a long-standing problem; some progress has been made in recent years by using light-front methods. Some aspects of bound states and long-range correlations in QFT can also be approached through all-order perturbative methods, based on a resummation of perturbative expansions.

Many divergence problems of QFTs can be avoided by formulating them in a finite volume and/or on a space-time lattice. Such studies give insight into the non-perturbative dynamics, allowing simulations to provide numerical answers for the properties of bound states. These studies can also be done at finite temperature, and are now widely used to study phase transitions, including the one between a hadron gas and the quark gluon plasma.

Investigations into quantum field theory are carried out in all groups participating in the programme (KUN, RUG, UL, UvA, UU and VUA).

Phenomenology

Work in particle phenomenology has strong roots in, and is closely interwoven with, quantum field theory. This is particularly evident for the strong and electroweak interactions in the standard model of particle physics.

In strong interaction physics perturbative calculations have proven to be indispensable for interpreting high-energy scattering experiments. High-order diagrammatic calculations have been undertaken in QCD, and Born level calculations hav been performed for processes in which many jets are produced in hadron collisions. For such calculations tools have been developed, such as the algebraic manipulation programmes which are able to handle very large algebraic calculations on the computer. Knowing the corrections, one is able to extract distribution and fragmentation functions, which are key quantities for our understanding of the quark and gluon dynamics in hadrons.

In turn this stimulated developments to understand the results via effective field theories in QCD, lattice calculations, or models incorporating essential symmetries, such as chiral symmetry. The use of effective field theories has also been instrumental to understand low-energy hadronic reactions and relativistic effects in nuclear physics.

In electroweak field theory new concepts and methods have been developed. These include e.g. an improved understanding of the Sudakov logarithms in broken gauge theories (which will be very important for future high-energy linear colliders) and the treatment of the effects of instability of either outgoing particles (e.g., W-bosons), or incoming particles (as in muon colliders). Advances have been made in the related field of numerical methods, both theoretically in the study of discrepancy distributions and applied in the construction of novel MC algorithms.

Other research projects in phenomenology include studies of heavy-quark production, in particular single-top production to measure the top-W coupling; Higgs production in hadron colliders; and furthermore the development of new ways to use polarization and particle production to map out the quark and gluon spin structure in a nucleon. The study of finite temperature field theories finds applications in heavy-ion collisions looking for the quark-gluon plasma. As concerns studies of particle phenomenology beyond the standard model, we mention studies of supersymmetric particle production at hadron colliders.

Research in particle phenomenology is carried out in Amsterdam (VUA), in Leiden (UL), in Utrecht (UU) and Nijmegen (KUN).

Quantum gravity and string theory

A quantum theory of gravity does not yet exist, but many valuable ideas have been developed in the context of simplicial gravity, canonical gravity, supergravity and string theory. Canonical gravity in 2, 3 or 4 dimensions, quantum black holes and Hawking radiation provide concrete models of gravitational physics incorporating essential quantum aspects. Supergravity has been studied as an effective theory of particle physics close to the Planck scale and/or an effective long-range field theory for strings.

In recent years important progress in string theory and supergravity has been made thanks to the discovery of new and powerful symmetries, called dualities, which relate strongly coupled theories (difficult to handle) to well-understood weakly coupled theories. It was realized that different formulations of string theory are in fact all related, being particular limits of a single underlying theory called M-theory. Although the precise formulation of this M-theory is not yet known, the study of its properties has provided a wealth of new information about a vast range of systems. Essential in these developments has been the so-called D-brane description of the extended solitons of string theory; it has also stimulated renewed interest in the theory of open strings.

Research has focused on three important and closely related aspects: the first is to try to find the formulation of M-theory that underlies all of string theory, and to investigate its consequences for the structure of space and time. It is hoped that the recent breakthroughs in black hole physics will lead to a concrete synthesis with other ideas in particular the holographic principle of 't Hooft. The second is to use the newly discovered techniques to tackle important and unresolved questions concerning the physics of elementary particles, in particular those related to the strong interactions and the question of supersymmetry breaking. Finally, the D-brane scenario has been picked up by cosmologists to formulate new models for the evolution of the universe.

It should be stressed that the study of string theory is not an isolated endeavour into Planck-scale physics and cosmology. There have been various developments in the context of string theory which have become independent fields of research, where a fruitful exchange of ideas and research results with other parts of theoretical physics takes place. For example, conformal field theory has many interesting applications in statistical mechanics and condensed matter physics, such as in the description of critical phenomena, turbulence and impurity problems.

Contributions to canonical and supergravity and/or the theory of strings and M- theory, D-branes and conformal field theory have been made by the groups in Amsterdam (UvA), Groningen (RUG), Leiden (UL) and Utrecht (UU). In view of the broad spectrum of activities in this research field, it was decided that a new nationally coordinated research programme *String Theory and Quantum Gravity* would be formulated and submitted to the FOM. In the meantime the Executive Board of FOM has approved this as one of its programmes (FP57), which will run for 8 years. Dijkgraaf is programme manager. We will not further expand on the plans described in this programme as it has now acquired an independent status.

2.2 The projects performed in FOM working groups

Overview

For phase I (1998-2002) of the programme Fundamental Interactions in total 10 Ph.D. positions (40 PhD-years) and 12 postdoc-years were requested. At the start some running positions from the former 'werkgemeenschap Theoretical High-energy physics' were also financed in the programme.

The proposed division for the Ph.D. positions was 4 positions in Quantum Field Theory, and 3 positions each in Phenomenology and Strings/Gravity. A more or less equal division of the postdocs among the three themes was foreseen.

Of the foreseen 10 PhD positions (40 PhD-years) in phase I, actually 24 PhD-years had been used up to january 2002. Another 12 PhD-years are in the presently running contracts. This means that 9 PhD positions are committed.

Of the 12 postdoc-years, 9 have been used up to january 2002. Another 8 postdoc-years are in the presently running contracts. This means that in total 17 postdoc-years are committed.

We note that actually only 40 % of the positions has fully ended as of January 1, 2002. In particular most PhD-positions, which run for four years, have not yet been completed. Of all of the completed and running positions factual data from year to year such as publications and invited talks can be found in the FOM year reports.

We feel that a balanced division of the positions over the three themes has been reached. Since the programme covers a wide field, in phase I actually all of theoretical high-energy physics performed at the university groups in the Netherlands, one cannot expect full coverage. In the subsections below we give an overview of the positions that are actually financed from the programme FP31 (including positions in the former 'werkgemeenschap' Hth, that were still running at the start of FP31 on January 1, 1999). Since it may be hard to judge these data without seeing the embedding into the full research efforts of the university groups, we repeat the results in the appendix A but then embedded in the full information on the groups.

University of Amsterdam (UVA): FOM-A-01

staff	dates		field	remarks
prof.dr. J. Smit	permanent staff		QFT	

postdocs	dates	working with	field	remarks
dr. M. Alishahiha	1/12/2000-1/8/2001		Strings	partly FOM 99HT02
dr. S. Bilke	8/12/1997-8/12/1999	Smit	Gravity	
dr. J.I. Skullerud	1/10/2001-1/10/2003	Smit	QFT	running

Ph.D. students	dates	supervisor	field	remarks
drs. N.M. Muller	1/2/1994-1/2/1998	Bais	QFT	Hth-A
drs. M. Sallé	1/2/1998-1/2/2002	Smit	QFT	running
drs. J. Striet	1/5/1999-1/5/2003	Bais	QFT	running
drs. R.H. Boels	1/8/2001-1/8/2005	de Boer	Strings	partly FOM 99HT02

Completed FOM-FP31 (or Hth-A) Ph.D. degrees in Amsterdam (UVA), 1998-2001.

1. N.M. Muller, *"Topological Interactions and Quantum Double Symmetries"*, promotor: prof. dr ir F.A. Bais, University of Amsterdam, Amsterdam, 2 October 1998, ISBN 90-5776-008-8.

Publications in FP31: see appendix B.1

- J. Smit: 1, 16-18, 20-21, 33-34, 38-39, 56, 71-76
- M. Alishahiha: 61-62
- S. Bilke: 5, 6, 23-25
- J.I. Skullerud:
- M. Sallé: 71-76
- J. Striet: 57
- R.H. Boels:

The research at the UVA group is roughly divided in two parts. One part is concerned with String Theory and Quantum Gravity, which is now part of the FOM programme FP57. The other part concerns the investigation and application of non-perturbative aspects of QFT.

Post-doctoral researcher S. Bilke carried out non-perturbative investigations in simplicial gravity, using the formulation of dynamical triangulation and numerical simulations. This is a direct geometrical approach to quantum gravity, although its two-dimensional analogue is related to string theory through the theory of random surfaces. Bilke investigated whether a sufficient of matter in the form of gauge fields could induce a new phase in the four-dimensional model, with improved (less spiky) geometries, as has been suggested by considerations based on the conformal anomaly. In Amsterdam he also improved the algorithm in order to reduce finite size effects. The resulting geometries were not found to have improved in their smoothness properties, although other groups in Japan found different results. After some eight years of intense investigation by various groups around the world (including J. Smit and his PhD-student B.V. de Bakker), this approach appears to have reached its computational barrier, for the time being.

Recently postdoctoral researcher J.I. Skullerud and J. Smit started a project using numerical simulations for studying baryon production through skyrmion formation in heavy-ion collisions.

PhD-student M. Sallé and J. Smit (together with J.C. Vink) have investigated thermalization in quantum field theories, using numerical simulation. The Hartree approximation is sufficiently simple to allow for the incoporation of inhomogeneous systems, such that topologically non-perturbative configurations can be dealt with. This has enabled them to study the scattering of quantum kinks in 1+1 dimensions. For homogeneous systems, thermalization properties were found to be much improved in a 'Hartree ensemble approximation', which exploits inhomogeneous mean fields.

The PhD project of J. Striet focusses on subtle but fundamental effects that topological interactions may have also in four dimensions. To that end it was decided to study as a class of nontrivial but representative examples, Alice electrodynamics theories with gauge group U(1) $\otimes$ Z_2, where the Z_2 of Charge conjugation is locally gauged. These theories feature alice fluxes, cheshire charges etc. New models have been constructed by us (ref. 57 in appendix B1). A study is made of the phase structure of these models. We have demonstrated the core instability of 't Hooft Polyakov monopoles in these theories (hep-th/0205152). Also quantum effects, like screening by alice flux loops are under investigation, which may in 3 dimensions lead to the decay of charge. The work has analytical as well as substantial numerical components.

Rijksuniversiteit Groningen (RUG): FOM-G-01

Postdocs	appointment dates	working with	field	remarks
dr. J.C.R. Bloch	1/9/96-1/9/98	Atkinson	QFT	Hth-G
dr. U.G.V. Gran	1/10/01-1/10/03		Strings	running

Ph.D. students	appointment dates	supervisor	field	remarks
B. Janssen	1/9/94-1/9/98	de Roo/Bergshoeff	Strings	Hth-G
A.H. Hams	1/9/96-1/9/98	Atkinson	QFT	Hth-G
E.A. Eyras	1/9/95-1/12/99	Bergshoeff	Strings	
J.P. van der Schaar	1/9/96-1/9/00	Bergshoeff	Strings	
T.C. de Wit	1/10/99-1/10/03	Bergshoeff	Strings	running

Completed FOM-FP31 (or Hth-G) PhD degrees in Groningen (RUG), 1998-2001

1. B. Janssen, *Dualities of Strings and Branes*, University of Groningen, 12 june 1998 (Promotor: Prof.dr. D. Atkinson, referenten Dr. E.A. Bergshoeff, Dr. M. de Roo)

2. E.A. Eyras, *Brane Dynamics in Diverse Backgrounds*, University of Groningen, 11 june 1999 (Promotor: Prof.dr. D. Atkinson, referenten Dr. E.A. Bergshoeff, Dr. M. de Roo)

3. J.P. van der Schaar, *String Theory Limits and Duality*, University of Groningen, 30 june 2000 (Promotor: Prof.dr. D. Atkinson, referenten Dr. E.A. Bergshoeff, Dr. M. de Roo)

Publications in FP31: see appendix B.2

- U.G.V. Gran: 65
- E.A. Eyras: 9, 14, 29-30, 33-34
- J.P. van der Schaar: 11, 15, 21-22, 27, 33, 39-40, 55-56
- T.C. de Wit: 34

In the period 1998-2001 the research programme of the group in Groningen centered on the following topics:

- Branes, and in particular domain walls (branes which D-2 spatial extensions in a D-dimensional spacetime) have played an important role in our research programme and have become a recurrent theme in our field. For instance, in the Randall-Sundrum scenario our universe is a domain wall in a five-dimensional spacetime. The AdS/CFT correspondence can be extended to domain walls, and our group contributed to this Domain Wall/Quantum Field Theory correspondence.

- The dynamics of D-branes have been investigated. This resulted in a complete action for D-branes. Recently we have attempted to extend this work to the case where the fields on the branes include Yang-Mills fields, as in the Standard Model. Work along these lines is being continued at present.
- There is observational evidence for a small positive cosmological constant (de Sitter spacetime). The Randall-Sundrum scenario is hard to reconcile with supersymmetry, which is an essential part of string theory. We have made a specific proposal how to circumvent no-go theorems in this context.
- A intriguing aspect of branes is that, in a particular limit, the geometry on the brane becomes a so-called noncommutative geometry, in which coordinate functions no longer commute. The coordinates involved are the points where strings are attached to the brane. In the case of rolled-up membranes ending on higher branes the intersection is a circle, and we have shown that this gives rise to a noncommutative geometry of loops. This work has an interesting interface with mathematics, since not much is known about such geometries.

University of Leiden (UL): FOM-L-01

Staff	appointment dates		field	remarks
Prof. Dr. P.J. van Baal	up to 2001		QFT	
Postdocs	appointment dates	working with	field	remarks
Dr. T.G. Kovács	09/1998 - 09/2000	van Baal	QFT	
Dr. F.M.L.C. Freire	05/2002 - 05/2004	Achúcarro	QFT/Part-Astroph	running
Ph.D. students	appointment dates	supervisor	field	remarks
Dr. A.P. Chapovsky	02/1996 - 12/1999	Berends	Phenomenology	
J. Schweizer	09/2000 - 06/2001	van Neerven	Phenomenology	stopped

Completed FOM-FP31 (or Hth-L) Ph.D. degrees in Leiden 1998-2001.

1. A.P. Chapovsky, *Instability and radiative corrections in pair production of W-bosons*, 23 september 1999, Univ. Leiden, promotor: Prof. Dr. F.A. Berends, co-promotor: Dr. W.J.P. Beenakker.

Publications in FP31: see appendix B.3

- P. van Baal: 13-19, 41-43, 70-71, 85-87
- T.G. Kovács: 39-40, 63-68, 85
- F.M.L.C. Freire (has just started pd position)
- A.P. Chapovsky: 6, 32-35, 53
- J. Schweizer (stopped with PhD after 8 months)

The research topics in the Ht-L working group for this period fall under the themes 'Phenomenology' and 'Quantum field theory'. It also included 'Quantum gravity and string theory', in particular in the period that Jan de Boer was in Leiden on a FOM-springplank position.

In the work of Kovács (with van Baal) results on the instanton, monopole and vortex content for the low-energy description of QCD were obtained, that help in developing both a quantitative and qualitative picture of confinement. These non-perturbative studies of QCD have a numerical component, mainly in the use of lattice gauge theory, that was supported by a grant from NCF for the use of the CRAY at SARA. The size distribution of instantons (with M. García Pérez), the interaction of instantons with quarks using improved lattice actions, and vortex studies (with E.T. Tomboulis) were important aspect of our work. Lattice methods were also used to study calorons and instantons in a finite volume (with

M. García Pérez, A. Gonzalez-Arroyo, A. Montero and C. Pena). We were even able to implement the Nahm transformation numerically on a lattice, which led to interesting results on T-dualities in gauge theories.

The presently running postdoc position in Leiden (J. Freire) will contribute to the field in which A. Achúcarro is working. The work will focus on the physics of topological defects and extended objects, like semilocal strongs, their role in the early universe and their possible appearance in particle accelerators. Some of these studies will involve extensive numerical simulations.

In the work of Chapovsky (with Beenakker and Berends) results on the treatment of unstable particles in the phenomenological calculations for high energy colliders were obtained. Part of the results were based on the calculation of the complete $\mathcal{O}(\alpha)$ QED correction for the process $e^+e^- \to W^+W^- \to 4f$ computed within the so-called pole-scheme. In particular, this was applied to calculate $\mathcal{O}(\alpha_S)$ non-factorisable QCD corrections for top-quark pair production. It was found in a qualitative study that one-loop non-factorisable corrections are suppressed at high energies at least as E^{-4} when compared to the Born cross-section. Furthermore, a technique was developed, which allows to perform gauge invariant calculations for the processes involving unstable particles, so as to perform Dyson resummations in a gauge invariant way. This technique is based on the use of (gauge invariant) nonlocal effective Lagrangians, allowing for quite a general and uniform treatment of all particles of the Standard Model.

University Nijmegen (KUN): FOM-N-01

staff	dates		field	remarks
Dr. W. Beenakker	2001-2002		Phenomenology	
Ph.D. students	dates	supervisor	field	remarks
A. van Hameren	up to 01/2001	Kleiss	Phenomenology	
C. Dams	from 10/2000	Kleiss	Phenomenology	running

Completed FOM-FP31 (or Hth-N) Ph.D. degrees in Nijmegen (KUN), 1998-2001.

1. A.F.W. van Hameren, *Loaded dice in Monte Carlo: importance sampling in phase space integration and probability distributions for discrepancies.*, Jan 2001. 160pp. Advisor: Prof. dr. R.H.P. Kleiss. e-Print Archive: hep-ph/0101094

Publications in FP31: see appendix B.4

- W. Beenakker: 20-21
- A. van Hameren: 10, 12, 14-17, 19
- C. Dams: 7

The research topics in the Hth-N working group fall under the themes 'Phenomenology' and 'Quantum field theory'. In connection with the past performance in FP31 we mention

- In the field of Monte Carlo integration, the nonuniformity properties of multidimensional point sets have been studied with the help of quantum field theory. This is an important result for the quality assessment of so-called quasi-random point sets and sequences. On the more applied side, we have constructed new Monte Carlo algorithms for generating the spacetime structure of QCD antennae (the SARGE algorithm) which allows for a much improved MC determination of multijet cross sections at for instance the LHC (A. van Hameren)

- Various aspects of quantum field theory in zero dimensions have been investigated, such as exact solutions and perturbativity for complex values of the coupling constants (A. van Hameren). A new class of so-called recursive actions has been discovered in which the amplitude generating function takes on a particularly simple form, and sometimes higher loop corrections vanish for any number of external legs (A. van Hameren, C. Dams)

- One-loop QCD corrections for $t\bar{t}H$ hadroproduction have been computed, with a substantial stabilization of the theoretical prediction for this important LHC process. In addition, an EW two-loop investigation has confirmed exponentiation of Sudakov logarithms in the Standard Model, and shown that transverse and longitudinal degrees of freedom exponentiate in a different manner, in contrast to previous claims (W. Beenakker)

University Utrecht (UU): FOM-U-01

Postdocs	appointment dates	worked with	field	remarks
dr. V. Shevchenko	1/07/2001-1/7/2003	Tjon	QFT	running
dr. S. Stanciu	1/10/1999-1/10/2001		Strings	

Ph.D. students	appointment dates	supervisor	field	remarks
drs. G.T.J. Zwart	1995 - 1999	E. Verlinde	string theory	Hth-U
drs. B.J.K. Kleijn	1/9/1994 - 1/9/1998	de Wit	supergravity	Hth-U
drs. V. Pascalutsa	1/9/1994 - 1/9/1998	Tjon	Phenomenology	Hth-U
drs. G.A.P.T. Aarts	1/10/1995 - 1/10/1999	Smit	QFT	
drs. J. Weda	1/9/1999 - 1/9/2003	Tjon	QFT	running
drs. J. Käppeli	1/4/1999 - 1/4/2003	de Wit	Strings	running

Completed FOM-FP31 (or Hth-U) Ph.D. degrees in Utrecht (UU), 1998-2001.

1. Kleijn, B.J.K.: New couplings in $N = 2$ supergravity. Promotor: B. de Wit. Utrecht, May 25, 1998.
2. Pascalutsa, V.: Covariant description of pion-nucleon dynamics. Promotor: prof.dr. J.A. Tjon. Utrecht, October 19, 1998.
3. Zwart, G.T.J.: *String perspectives on gauge theories.* Promotor: prof.dr. E.P. Verlinde, Utrecht, November 29, 1999.
4. Aarts, G.A.P.T.: *Dynamics in equilibrium and nonequilibrium quantum field theory*, Promotor: prof.dr. J. Smit. Utrecht, October 4, 1999.

Publications in FP31: see appendix B.5

- S. Stanciu: 99-100, 113-114, 146
- V. Shevchenko: running
- G.A.P.T. Aarts: 1-4, 47-48, 87-88
- J. Weda: running
- J. Käppeli: 127-128

The research of Stanciu has focused on the study of D-branes in general string backgrounds. A specific class of such theories was considered, namely the study of D-branes in string backgrounds based on group manifolds and coset spaces, using a combination of different methods: the microscopic approach based on the techniques of boundary conformal field theory, the more standard field theoretic approach based on sigma models and the path integral, and the one based on the Born-Infeld action. In this way, one can investigate the possible D-brane configurations in a number of concrete string backgrounds, and analyse their geometry, spectrum and stability. The knowledge gained about the geometry of D-branes in group manifolds allows a proposal for the D0-charge of a particular type of such D-branes, which is manifestly gauge invariant, quantised and whose modularity properties agree with the predictions of twisted K-theory.

Weda (with J. Tjon) investigated confinement and chiral symmetry breaking in heavy-light quark systems using the Bogoliubov-Valatin variational method, after which he shifted to the calculation of one gluon exchange in light mesons and baryons. For this an effective quark Lagrangian derived by applying the formalism of field correlators and considering the large N_c limit is used to obtain equations for the confined quarks. One gluon exchange is then calculated using perturbation theory. Research is going on to nonperturbative one gluon exchange and other properties of the generated quark systems.

Käppeli (with B. de Wit) analyzed a broad class of stationary solutions with residual N=1 supersymmetry of four-dimensional N=2 supergravity theories with terms quadratic in the Weyl tensor. The solutions include extremal black holes and rotating field configurations, and may have multiple centers. They can be expressed in terms of harmonic functions associated with the electric and magnetic charges carried by the solutions by a proper generalization of the so-called stabilization equations. Proof was given that spacetimes with unbroken supersymmetry is fully determined by the charges. This result establishes the so-called fixed-point behavior according to which the moduli fields must flow towards certain prescribed values on a fully supersymmetric horizon, but now in a more general context with higher-order curvature interactions.

The properties of the classical approximation for quantum field dynamics were further elucidated by J. Smit and his PhD-student G. Aarts, at Utrecht University. They also devised a method for incorporating fermions in numerical simulations in real time. The effect of sphaleron transitions on fermion number was studied numerically in the abelian-Higgs model with dynamical fermions in 1+1 dimensions. Tests were carried out in the same model showing, remarkably, effective thermalization to take place from non-equilibrium initial conditions.

Vrije Universiteit Amsterdam (VUA): FOM-V-01

Postdocs	dates	working with	field	remarks
Dr. R. Kundu	01/10/2000-01/12/2001	Mulders	Phenomenolgoy	
Dr. A. Metz	01/12/2001-01/07/2002	Mulders	Phenomenology	partly EU

Ph.D. students	dates	supervisor	field	remarks
Drs. N. Schoonderwoerd	15/12/1995-01/03/1999	Bakker	QFT	Hth-V
Drs. M. van Iersel	01/08/1999-01/08/2003	Bakker/Mulders	QFT	running

Ph.D. degrees awarded in Amsterdam (VUA), 1998-2001.

1. N.C. Schoonderwoerd, *Light front hamiltonian field theory; towards a relativistic description of bound states*, 14 Jan. 1999, Vrije Universiteit. Promotor: Prof. dr. P.J.G. Mulders; copromotor: Dr. B.L.G. Bakker.

Publications in FP31: see appendix B.6

- R. Kundu: 44
- A Metz: 44, 53
- M. van Iersel: 39

In the VU theory group working in particle physics, a number of topics are addressed belonging to themes 'Quantum field theory' (such as lightcone quantization) and 'Phenomenology' (such as deep inelastic scattering).

- A research line included in the phenomenological studies on *deep inelastic scattering* is the inclusion of effects of parton intrinsic transverse momentum. This gives rise to azimuthal asymmetries, in particular in polarized processes. For this a detailed analysis of quark distribution and fragmentation functions in polarized hadrons has been made. The postdocs R. Kundu (left after slightly more than one year to take a position in India) and A. Metz (position still running) have contributed to this research topic with a specific model calculation for the time reversal-odd Collins fragmentation function, which appears in single spin asymmetries in deep inelastic scattering.

- Under *lightcone quantization*, the quantization in front form is studied, which is in principle equivalent to instant form quantization. In practice many details remain to be studied because one needs different regularizations or has to deal with zeromodes in front form quantization. For QCD front form quantization may be a promising route, because the wave functions in the hamiltonian formulation can be directly connected to the quark distribution functions in deep inelastic scattering. The work of the graduate student M. van Iersel (running position in FP31) deals with the equivalence of the two forms of quantization, investigated in particular by considering the various aspects in a simple scalar field theory.

3 Future plans (Phase II of FP31)

3.1 Introduction

The programme FP31 based at the universities has strong thematic links with the programme FP52 based at NIKHEF. In addition, the programme *String theory and quantum gravity* (FP57) co-ordinating all research in these fields, has recently been approved. The physicists involved in these three programmes form since January 1, 2002, the FOM Network for Theoretical High-Energy Physics. Programmes and network have an important impact on research and training in this branch of theoretical physics. All active theoretical high-energy physicists in the Netherlands participate in one or several of the programmes. The programmes plan to continue the various joint activities (see section 1) as well as the organisation of workshops, conferences, graduate schools and summer schools.

Like in other branches of physics, developments in theoretical high-energy physics are fast and sometimes unexpected. To stay in the forefront of research the programme of the Dutch research community must be flexible and innovative. Compared to the originally approved programmes FP31 and FP52, for the next few years we propose the continuation of successful projects as well as the exploration of new areas of research. Projects in FP31 will center around topics in quantum field theory and particle phenomenology and will explore possible new areas in astroparticle physics. It is to be stressed that, as before, these topics are closely interwoven, and researchers often work in more than one field. We provide a brief overview of active developments in each area in turn.

3.2 Quantum field theory

After many years of development quantum field theory (QFT) is still the essential framework, remaining a field full of new ideas and surprises. Fundamental problems in quantum field theory can be identified both in the perturbative and non-perturbative regime.

1. In perturbatively renormalizable QFT an important objective is to find analytic expressions for Feynman diagrams with an arbitrary number of loops. In recent times considerable progress in this direction has resulted from the study of the properties of Mellin transforms and harmonic polylogarithms. The structure of multi-loop diagrams will be further investigated by van Neerven (UL) and Vermaseren (NIKHEF) under the programmes FP31 and FP52.

2. The presently ongoing project in lightcone field theory by Bakker (VU) is the study of front form quantization as a possible nonperturbative approach to study bound state dynamics in field theories. The developments are aimed at applications in QCD to study quark and gluon distribution and fragmentation functions.

3. On the non-perturbative level, non-trivial topological configurations of gauge theories imply the existence of stable objects or well-defined excitations such as monopoles, vortices and instantons. The study of the spectrum and properties of these topological excitations has revealed rich underlying branches of mathematics involving intricate geometrical and group-theoretical structures. Quantum groups and Hopf algebras have been found to play a rôle. Dualities between electric and magnetic charges and phases, as well as between strong- and weak-coupling regimes shed light on the various realizations of symmetries and the phase structure of these theories. Bais and coworkers (UvA) plan specific investigations of such topological properties of quantum field theories, especially in 2 and 3 dimensions. New developments in the classification of the phases of non-abelian (topological) field theories and the related breaking of quantum symmetries have exciting consequences and will be studied in the programme FP31.

4. The quest for understanding of QFT in the perturbative and non-perturbative regimes has stimulated studies of QFT at finite temperature, volume and/or density. Van Baal (UL) investigates non-perturbative aspects of field theories at finite temperature and in finite volume with the aim of increasing the understanding of the relations between different types of topological excitations. An effort to clarify the rôle of self-dual solutions known as calorons will be made. Furthermore, he intends to extend these studies to supersymmetric field theories in finite volume. Because of the sensitivity of such field theories to the global topology of the configuration space, it is expected that topological effects will have a large impact on non-perturbative dynamics.

5. We also mention possible follow-up studies of some work of 't Hooft (UU) on fundamental issues in quantum theories. In recent years he has considered for instance the counting of planar diagrams. This study dealt with the asymptotic nature of certain sets of planar Feynman diagrams. The numbers of diagrams of various types and with various constraints can be expressed in terms of generating functions. Other possible studies are connected to fundamental questions in quantum mechanics, gravity and its quantisation in $2 + 1$ dimensions, general relativity, instantons or some technical aspects related to QCD such as resummation issues.

6. Non-perturbative methods based on Schwinger-Dyson hierarchies, and generalizations of 2PI effective-action techniques such as Φ-derivable approximations, form the basis of numerical simulations of qantum fields in real time. These methods can be applied to systems at finite temperature as well as out of equilibrium. The application to quantum gauge fields in real time is still in its infancy.

   The classical approximation continues to be very useful for studies of defect formation in phase transitions. Examples are baryon production by skyrmion formation in heavy-ion collisions, and by electroweak sphaleron transitions. This approximation can also be used for studying the onset of thermal behavior, which is crucial for understanding the initial conditions that are being used in the successful hydrodynamical description of of recent experimental results at RHIC. Smit (UvA/UU) continues these investigatons using analytical and numerical techniques.

7. Boer (VUA) has recently started to investigate topological (instanton) aspects of the phase diagram of QCD, in particular regarding the color superconducting phase and the possibility of spontaneous CP violation in QCD, including the relation to heavy ion collisions and the physics of neutron stars.

3.3 Phenomenology

The applications of quantum field theory to the realm of particle physics provide a rich source of research problems, of importance both to the analysis of existing and the planning of future experiments. Particular topics to be studied are found in the area of the standard model, as well as in possible physics beyond the standard model.

1. The single most important topic in electroweak interactions at present is the mechanism of symmetry breaking and the properties of the Higgs particle(s). The experiments planned at the Tevatron, LHC and future linear electron-positron colliders all aim to establish the existence of the Higgs particle and measure its mass and couplings to quarks and leptons. These studies will reveal the nature

of spontaneous symmetry breaking in the electroweak interactions. Signals for the production of a Higgs boson, and the separation of signal and background, require the computation of radiative corrections due to strong interactions (QCD) in next-to-next-to-leading order (NNLO). Such high-order corrections in QCD involve multi-loop diagrams as computed by van Neerven (UL) and Vermaseren (NIKHEF), who has developed the widely used computer algebra programme FORM for such purposes.

2. A quantity of particular importance is the NNLO total cross section for hadron-hadron scattering, which is required to improve our understanding of Higgs-boson production at hadron colliders like Tevatron and LHC. Van Neerven (UL) has undertaken a computation of this total cross section, valid also in the domain of large Higgs boson mass ($m_{Higgs} \sim m_{top}$), which is to be completed under the present programme.

3. Another important development in electroweak physics is the recent strong evidence for neutrino masses and oscillations. Apart from its intrinsic interest and the opening up of new channels for CP-violation in the context of the standard model, it has profound implications for the production and spectrum of neutrinos from astrophysical sources. Gaemers (UvA/NIKHEF) and van den Horn (UvA) study the physics of neutrinos and the astrophysical processes in which they are produced. Also Mulders (VUA) plans studies on neutrinos not only from astrophysical but also from terrestrial sources such as a possible future neutrino factory.

4. Application of field theoretical techniques to QCD require dedicated effort. In order to arrive at a reliable prediction of multijet QCD processes, as well as processes involving both QCD and electroweak interactions, it is necessary to understand the colour structure of the cross section. Kleiss (KUN) intends to study colour flow in multijet processes. For accurate MC simulation of complicated processes with many external particles, adequate phase-space algorithms need to be developed. Also, for processes with many external legs, described by extremely large numbers of Feynman diagrams, explicit diagram-by-diagram evaluation quickly becomes impractical. The successful Caravaglios-Moretti algorithm to compute large tree-level amplitudes needs, if at all possible, to be extended to include loop corrections without invoking the effective action. The feasibility of such an approach will be investigated.

5. Not only in QCD, also in electroweak theory resummation improves the behaviour of perturbative expressions for physical quantities. High-order corrections will be of particular importance at future (linear) colliders. Beenakker (KUN) is involved in such calculations, with special emphasis on large doubly-logarithmic (Sudakov) effects.

6. The structure of hadrons, in particular the proton, is quite complicated, but within the framework of QCD well-defined objects, matrix elements of quark- and gluon fields, can be isolated in high-energy scattering processes such as distribution and fragmentation functions. The study of the quark spin and flavour structure of these functions has uncovered an intriguing role for the intrinsic transverse momenta of partons. These are found in azimuthal asymmetries in high-energy semi-inclusive processes, which actually have been observed in LEP (CERN) and HERMES (DESY) experiments. This makes the study of the factorization properties within the framework of QCD necessary. This will become the focus of new theoretical studies of Mulders and Boer (VUA).

7. The study of the baryon (meson) - baryon interactions will remain the main subject of Rijken (KUN). With the coming of the Japan-Hadron-Facility (JHF) in 2006, the study of baryon-baryon interactions will enter a new era. The detailed description and understanding of these interactions will be basic for the analysis of the new experiments and the possibility for progress in the theory of nuclear- and stellar- structure. In particular strange matter will be an important topic.

8. New physics beyond the standard model, such as supersymmetry, implies the existence of a more complicated Higgs sector, involving also new pseudoscalar particles. The computation of their coupling through radiative corrections requires a proper treatment of γ_5 and the ϵ-tensor in regularized

perturbation theory, in particular in the presence of IR and collinear divergences. This problem will be addressed by van Neerven (UL).

3.4 Astroparticle physics

Increasing amounts of precise and exciting data on astrophysics and cosmology have opened up the study of applications of field theory and particle physics to the dynamics and evolution of the universe at large. The observed expansion and flatness of the universe, deduced from the recent measurements of the redshift of distant supernovae and the fluctuation spectrum of the cosmic microwave background, provide evidence for an epoch of inflation and the existence of dark energy, including a cosmological constant. Studies of the proper motion of stars in galaxies, and of galaxies in clusters point to the existence of large amounts of non-baryonic dark matter, the nature of which is presently completely unknown. Speculations run from black holes to weakly interacting heavy neutral particles, such as are predicted e.g. by supersymmetric extensions of the standard model.

New states of ordinary baryonic matter can arise under extreme pressure and density, as in neutron stars, or at extreme density and temperature, as in the early universe. Phase transitions can occur, driven for example by electroweak symmetry breaking, chiral symmetry breaking in QCD, or GUT-scale symmetry breaking close to the Planck scale. In such processes localizable or quasi-localizable extended objects can be formed, like monopoles and strings. All such processes can be modeled in analytical and numerical studies of field theories at finite density and temperature. Laboratory experiments in condensed matter systems can provide experimental tests of such calculations.

A special and important problem in this relation is the origin of baryonic matter, and the domination of matter over anti-matter. Its explanation must involve unusual but real field-theory and particle-physics effects, like CP-violation and non-equilibrium thermodynamics.

Research efforts in these directions in the context of the present programmes (FP31 and FP52) are to be stepped up.

1. Smit will continue to apply new insights in quantum fields in- and out-of-equilibrium to cosmology. It is highly suggestive that the CP violation in the standard model, which is made possible by the existence of three or more generations, and which has the right magnitude to explain the experimentally-observed CP violation, is also related to the baryon asymmetry. This CP violation is very small, but if there is inflation ending at the electroweak scale, the asymmetry can be enhanced by various non-equilibrium effects. We want to know what is the maximum baryon asymmetry that can be generated by standard model physics in an electroweak transition. The problem also relates to (pre)heating and thermalization after inflation.

   Of course, there are other appealing possibilities related to physics beyond the standard mode, e.g. baryogenesis through leptogenesis by heavy neutrino decay. One of the striking aspects of the problem of baryogenesis is its broad scope in bringing together many models and tools of theoretical particle physics.

2. We already mentioned the work of Boer (VUA), Koch (NIKHEF/UvA) on the phases and phase transitions in QCD, which have astrophysical and cosmological applications.

3. A. Achúcarro (UL) has recently been appointed in Leiden to study the cosmological phase transitions and the formation of topological excitations in such processes. The simulation of such processes in condensed matter systems has her special interest. Ch. van Weert (UvA) is also involved in studies of phase transitions in condensed matter systems.

4. Cosmic scalar fields can provide a mechanism to drive inflation and/or provide the dark energy necessary to explain the observed flatness of space. The origin and dynamics of such cosmic scalar fields may open up an observational window on Planck scale physics. Other windows on the universe at very early times are expected from the study of relic neutrinos and gravitational waves. Under the supervision of van Holten (NIKHEF) and 't Hooft (UU), Groot Nibbelink (NIKHEF) and van Tent (UU) have begun to investigate cosmological scalar fields and their rôle in driving inflation. Such studies will be extended in the near future.

5. At the intersection with string theory, scenarios for cosmology based on brane worlds have been developed recently and are presently under intense investigation. Supersymmetry, which is a desirable property from the phenomenological point of view, is hard to reconcile with these models. In a similar vein, supersymmetry and a positive cosmological constant, which is indicated by recent observations, do not go well together. Bergshoeff and de Roo plan to investigate these problems. The groups in Leiden, Amsterdam and Groningen will organize the International Workshop Branes and Cosmology at the Lorentz Center in Leiden in november 2002. One of the purposes of this Workshop is to stimulate interactions between the theoretical physics and astronomy communities in the Netherlands.

4 Programme summary and requested support

4.1 FP31: Fundamental interactions

The summary of the status at present is given in the following table, containing the actual number of postdoc and graduate student months spent in the years 1999, 2000 and 2001, the number of months committed because of currently employed postdocs and graduate students and the remaining number of months. The latter are estimated by FOM from the remaining budget. A proposal for the division by the programme leader has been indicated. Concentrating on the themes Quantum field theory and Phenomenology the proposal is 2 PhD positions for FOM-A-01 and FOM-L-01, one PhD and one postdoc for FOM-N-01 and FOM-V-01, one PhD student for FOM-U-01 and no positions for FOM-G-01.

location	total approved in proposal	finished (1999-2002)	running (committed 2002-2007)	plans [1)] (to be approved 2002-2007)	total (1999-2007)
Staff (months)	120	72	48	0	120
FOM-A-01		36	48	0	84
FOM-L-01		36		0	36
Postdocs (months)	240	103	105	48	256
FOM-A-01		23	21	0	44
FOM-G-01		3	21	0	24
FOM-L-01		20	27	0	47
FOM-N-01		12	12	24	48
FOM-U-01		30	18	0	48
FOM-V-01		15	6	24	45
OIOs (months)	816	291	143	336	770
FOM-A-01		72	35	96	203
FOM-G-01		58	21	0	79
FOM-L-01		20	0	96	116
FOM-N-01		39	33	48	120
FOM-U-01		70	35	48	153
FOM-V-01		32	19	48	99

Table 6.1: Employment of post-docs and PhDs in FP31.

The remaining positions for 2002-2007 are certainly not sufficient to cover all plans presented in section 3. In the following table we indicate a list of high-priority projects that has been discussed with the working group leaders. The numbers refer to the items listed in section 3.

group	position	supervisor	field	topic
FOM-A-01	oio	Smit	QFT/Astro-particle	3.2.6; 3.4.1
	oio	Bais	QFT	3.2.3
	pd*	Smit/Bais	QFT/Astro-particle	3.2.3; 3.2.6; 3.4.1
FOM-G-01	oio/pd*		Astro-particle	3.4.5
FOM-L-01	oio	van Baal	QFT	3.2.4
	oio*	Achúcarro	Astro-particle	3.4.3
	oio/pd	van Neerven	Phenomenology	3.2.1; 3.3.1; 3.3.2; 3.3.8
FOM-U-01	oio	't Hooft	QFT	3.2.5, 3.4.4
FOM-N-01	oio	Kleiss	Phenomenology	3.3.4
	pd	Beenakker/Kleiss	Phenomenology	3.3.5
FOM-V-01	oio	Mulders	Phenomenology	3.3.6
	pd	Boer/Mulders	Phenomenology/Astro-particle	3.2.7; 3.3.6

Table 6.2: Requested support in FP31

Following the division as indicated in table 6.1, the three positions indicated with $*$ cannot be included in the programme. This means that these and other initiatives of almost all groups in the direction of Astroparticle physics can only be done at the expense of the efforts in the other themes. In order to support the new initiatives in astroparticle physics a financial accress in FP31 would be needed or an immediate start towards the realisation of a new programme. Because of the close ties between the themes Quantum field Theory, Phenomenology and Astroparticle physics we prefer an accress within FP31.

Besides the positions a continuation of the material budget consisting of a part for the working groups involved (including FOM-G-01) and parts tied to the PhD and postdoc positions, in the same way as in the first phase of the programme is requested. This also allows for working group activities in years that there actually is no postdoc or Ph.D. student, among them activities as disseminating knowledge from projects and preparation for new initiatives and future programmes.

A Embedding of FOM programme FP31 at the universities

The activities in FOM programme FP31 are performed within FOM working groups at the six universities in the Netherlands, where physicists work in theoretical high-energy physics. Here we present an overview of activities in the various FOM working groups, mostly in tabular form. The activities restricted to the programme FP31 only have been given in section 2.

A.1 University of Amsterdam (UVA): FOM-A-01

staff	dates	employer	
prof.dr.ir. F.A. Bais		UvA	
drs. G.G.A. Bäuerle		UvA	
prof.dr. J. de Boer	from 1/9/2000	UvA	
prof.dr. R.H. Dijkgraaf		UvA	
prof.dr. K.J.F. Gaemers		UvA	
dr. L.J. van den Horn		UvA (CHEAF)	
prof.dr. J.H. Koch		NIKHEF/UvA	
dr. K. Skenderis	from 1/1/2003	UvA/NWO	
prof.dr. J. Smit		FOM FP31	
prof.dr. H.L. Verlinde	till 1/1/2000	UvA	
dr. J.C. Vink	1/10/1999-1/1/2002	UvA/FOM	
prof.dr. Ch.G. van Weert		UvA	

postdocs	dates	employer	topic
dr. M. Alishahiha	1/12/2000-1/8/2001	FOM FP31 FOM 99HT02	String field theory and tachyon condensation
dr. S. Bilke	8/12/1997-8/12/1999	FOM FP31	Fluctuating geometries and quantum gravity
dr. J.I. Skullerud	1/10/2001-1/10/2003	FOM FP31	Non-equilibrium field theories
dr. M. Serone	1/9/1998-1/9/2000	FOM 97PR1688	Anomaly cancelation for extended objects
dr. S. Terashima	1/9/2001-1/9/2003	FOM 97PR1688	Strings and K-theory
dr. M.A. Vazquez-Mozo	1/10/1998-1/1/2001	FOM 97PR1688	Nonperturbative string theory
dr. L. Cornalba	1/10/2001-1/10/2004	FOM 00PR1889	The physics of D-branes
dr. B.J. Schroers	1/9/1995-1/9/1998 1/9/1998-1/9/1999	NWO Pionier UvA	Non-abelian dualities

Ph.D. students	dates	employer	topic
drs. W.H. Tang	1/2/1993-1/2/1997	FOM Hth-A	Baryon number violation
drs. J.M. Smit	1/10/1991-1/10/1995	FOM Hth-A	Neutrinos in supernovae
drs. N.M. Muller	1/2/1994-1/2/1998	FOM Hth-A	Topology/quantum symmetries
drs. M. Sallé	1/2/1998-1/2/2002	FOM FP31	Non-equilibrium quantum fields
drs. J. Striet	1/5/1999-1/5/2003	FOM FP31	Alice electrodynamics
drs. R.H. Boels	1/8/2001-1/8/2005	FOM FP31 FOM 99HT02	String theory in time dependent backgrounds
drs. A.X. Arrizabalaga	1/9/1999-1/9/2003	FOM SF-A-b/3	Non-equilibrium dynamics of symmetry breaking
drs. J.A.E.F. van Dongen	1/2/1998-1/2/2002	NWO/Zeeman St./CHEAF	Einstein and unification
drs. R.J. Duivenvoorden	18/9/2000-18/9/2004	FOM 00PR1889	Strings/holography
drs. F. Hacquebord	1/1/1995-1/1/1999	NWO Pionier	Matrix string theory
drs. B.J. Nauta	1/7/1996-1/7/2000	UvA	High-T field theory

continuation			
Ph.D. students	dates	employer	topic
drs. J.S. Park	1/10/1995-1/10/1999	NWO Pionier	Cohomological field theories
drs. J.K. Slingerland	1/6/1998-1/6/2002	UvA	Hopf symmetries
drs. M. Temürhan	1/9/2001-1/9/2005	FOM 97PR1688	Holography
drs. A. Tranberg	1/10/2000-1/10/2004	UvA	Non-equilibrium QFT and early universe
drs. M.L. Vonk	1/10/1998-1/10/2002	FOM MF-A-a	Quantum gravity/strings/ gauge theories
drs. J.S. Wijnhout	15/4/2001-15/4/2005	FOM 97PR1688	Black holes/noncommutative geometry

Ph.D. degrees awarded in Amsterdam (UVA), 1998-2001.

1. N.M. Muller, *"Topological Interactions and Quantum Double Symmetries"*, promotor: prof. dr ir F.A. Bais, University of Amsterdam, Amsterdam, 2 October 1998, ISBN 90-5776-008-8.

2. J.M. Smit, *Neutrino Transport in Core-collapse Supernovae*, promotor: prof. dr E.P.J. van den Heuvel and prof. dr Ch.G. van Weert, copromotor dr L.J. van den Horn, University of Amsterdam, 20 May 1998, Universal Press, Veenendaal.

3. W-H. Tang, *Numerical Calculation of the Baryon Number Violation Rate in Hot Electroweak Theory*, promotor: prof.dr. J. Smit, University of Amsterdam, 1 September 1998, ISBN 90-5776-006-1.

4. F.H. Hacquebord, *Symmetries and Interactions in Matrix String Theory*, promotor prof.dr. H.L. Verlinde, Universiteit van Amsterdam, Amsterdam, September 22, 1999, 120p.

5. J.-S. Park, *Cohomological Field Theories on Complex Manifolds*, promotor prof.dr. H.L. Verlinde, Universiteit van Amsterdam, Amsterdam, November 23, 1999, 165p.

6. B.J. Nauta, *Dynamics of Gauge Fields at High Temperature*, promotor: prof.dr. Ch.G. van Weert, Universiteit van Amsterdam, Amsterdam, November 8, 2000, UvA, 128 pages, proefschrift.

Relevant developments at the university

The research in High Energy Theory at the UvA is mainly part of the Institute for Theoretical Physics (ITFA).

The String Theory group at the University of Amsterdam is a common initative of the institute for Theoretical Physics (ITFA) and the Korteweg-de Vries Institute for Mathematics (KdVI). It receives additional funds from the University Board through the Center of Mathematical Physics Amsterdam (CMPA, Dijkgraaf director), and external funding by FOM and NWO (GBE-Mathematics).

Amsterdam has from the beginning continuously supported this field, both from the mathematics and physics side. It was the first place in the Netherlands to offer permanent positions in this field (Dijkgraaf 1992, H. Verlinde 1994). With the aid of a NWO Pionier grant a number of infrastructure investments have been made. String theory is a main research theme in the research programme of both the ITFA and the KdV Institute and acts furthermore as a backbone of the CMPA.

String theory has a strong impact on and interaction with mathematics. This has been particularly encouraged in Amsterdam, and is reflected in the research profile at the KdV Institute. The recent appointments of Opdam and Landsman (with FOM support, also NWO pionier)) have strengthened this relation.

Dijkgraaf and J. de Boer are now heading the active research group in this field (H. Verlinde left per 1-1- 2000 to take up a full professorship at Princeton University, but is still associated to the UvA as visiting professor). A successful application was put in for a NWO Vernieuwingsimpuls grant for Kostas Skenderis. Skenderis is presently an Assistant Professor in the High Energy Theory group at Princeton

University and will become Associate Professor at the UvA. Skenderis' project will start September 2002. His grant will partly used to finance postdocs and graduate students.

In 2001, the University has awarded a *honorary professorship* to Nobel laureate Martinus Veltman.

Dr J.C. Vink was appointed in the group of Prof. J. Smit to strengthen the efforts in computational field theory. His presence was highly productive but unfortunately he left the Institute to work in industry.

Specific research topics, 1998-2001.

The research is roughly divided in two parts. One part is concerned with

- String Theory and Quantum Gravity. This research is now part of the FOM programme FP57.

The other part concerns the investigation and application of non-perturbative aspects of QFT and covers the following topics.

- Electroweak baryogenesis
- High temperature field theory and heavy ion collisions
- Computational Field Theory
- Topological defects and topological interactions
- Quantum group symmetries and their breaking

A.2 Rijksuniversiteit Groningen: FOM-G-01

Staff	appointment dates	employed by	
Prof.dr. D. Atkinson	until May 2000	RUG	
Dr. M. de Roo		RUG	
Prof.dr. E.A. Bergshoeff		RUG	
Postdocs	appointment dates	employed by	topic
Dr. J.C.R. Bloch	1/9/96-1/9/98	FOM Hth-G	Dyson-Schwinger equations
Dr. U.G.V. Gran	1/10/01-1/10/03	FOM FP31	Domain walls
Dr. P. Sundell	1/9/99-1/9/01	FOM 98PR1751	Noncommutative geometry
Dr. D. Berman	1/9/99-1/9/00	TMR	Noncommutative geometry
Ph.D. students	appointment dates	employed by	topic
B. Janssen	1/9/94-1/9/98	FOM Hth-G	Properties of branes
A.H. Hams	1/9/96-1/9/98	FOM Hth-G	Dyson-Schwinger equations, computational physics
E.A. Eyras	1/9/95-1/12/99	FOM FP31	Kaluza-Klein monopoles
J.P. van der Schaar	1/9/96-1/9/00	FOM FP31	Domain wall/QFT correspondence
T.C. de Wit	1/10/99-1/10/03	FOM FP31	Susy Randall-Sundrum scenario
R.S. Halbersma	1/7/98-1/7/02	FOM 98PR1751	Susy Randall-Sundrum scenario
M.G.C. Eenink	1/9/01-1/9/05	FOM FP57	Non-Abelian Born-Infeld
D. Roest	1/9/00-1/9/04	RUG	Massive dualities
A. Collinucci	1/9/01-1/9/05	RUG	Non-Abelian Born-Infeld

PhD degrees awarded in Groningen (RUG), 1998-2001

1. B. Janssen, *Dualities of Strings and Branes*, University of Groningen, 12 june 1998 (Promotor: Prof.dr. D. Atkinson, referenten Dr. E.A. Bergshoeff, Dr. M. de Roo)

2. E.A. Eyras, *Brane Dynamics in Diverse Backgrounds*, University of Groningen, 11 june 1999 (Promotor: Prof.dr. D. Atkinson, referenten Dr. E.A. Bergshoeff, Dr. M. de Roo)

3. J.P. van der Schaar, *String Theory Limits and Duality*, University of Groningen, 30 june 2000 (Promotor: Prof.dr. D. Atkinson, referenten Dr. E.A. Bergshoeff, Dr. M. de Roo)

Relevant developments at the university

D. Atkinson retired in May 2000. In 2001 E.A. Bergshoeff was appointed as his successor. In 2000 our European TMR network *Quantum aspects of Gauge Theories, Supersymmetry and Unification* ended, and was continued as the RTN programme *The Quantum Structure of Spacetime and the Geometric Nature of Fundamental Interactions*. In the TMR network David Berman (Durham) joined our group as a postdoc for one year, in the RTN network Mikkel Nielsen (Goteborg) will come to Groningen for two years, starting in 2002. Contacts with Goteborg and other Scandinavian universities have been strengthened by our participation in the Nordisk Forskerutdanningsakademi (NORFA) programme *SupersymmetriskaFält-och Strängteorier* (1999-present).

Specific research topics, 1998-2001

In the period 1998-2001 our research programme centered on the following topics:

- Branes, and in particular domain walls (branes which D-2 spatial extensions in a D-dimensional spacetime) have played an important role in our research programme and have become a recurrent theme in our field. For instance, in the Randall-Sundrum scenario our universe is a domain wall in a five-dimensional spacetime. The AdS/CFT correspondence can be extended to domain walls, and our group contributed to this Domain Wall/Quantum Field Theory correspondence.
- The dynamics of D-branes have been investigated. This resulted in a complete action for D-branes. Recently we have attempted to extend this work to the case where the fields on the branes include Yang-Mills fields, as in the Standard Model. Work along these lines is being continued at present.
- There is observational evidence for a small positive cosmological constant (de Sitter spacetime). The Randall-Sundrum scenario is hard to reconcile with supersymmetry, which is an essential part of string theory. We have made a specific proposal how to circumvent no-go theorems in this context.
- A intriguing aspect of branes is that, in a particular limit, the geometry on the brane becomes a so-called noncommutative geometry, in which coordinate functions no longer commute. The coordinates involved are the points where strings are attached to the brane. In the case of rolled-up membranes ending on higher branes the intersection is a circle, and we have shown that this gives rise to a noncommutative geometry of loops. This work has an interesting interface with mathematics, since not much is known about such geometries.

A.3 Universiteit Leiden (UL): FOM-L-01

Staff	appointment dates	employed by	topic
Prof. Dr. P.J. van Baal		FOM FP31/UL	QFT
Prof. Dr. F.A. Berends		UL	Phenomenology
Dr. W.L.G.A.M. van Neerven		UL	Phenomenology
Dr. W.J.P. Beenakker	03/1995 - 09/1998	KNAW-fellow	Phenomenology
Prof. Dr. J. de Boer	01/1999 - 09/2000	FOM Springplank	Strings
Prof. Dr. A. Achúcarro	*from 04/2002*	*UL/FOM*	*Astro-Particle*
Postdocs	**appointment dates**	**employed by**	**topic**
Dr. T.G. Kovács	09/1998 - 09/2000	FOM FP31	QFT
Dr. F. Bruckmann	since 10/2001	FOM 99PR1797	QFT
Dr. A. Vogt	09/1998 - 09/2001	EU	Phenomenology
Dr. C. Ford	since 07/2001	EU	QFT
Ph.D. students	**appointment dates**	**employed by**	**topic**
Dr. A.P. Chapovsky	02/1996 - 11/1999	FOM FP31	Phenomenology
J. Schweizer[1]	09/2000 - 05/2001	FOM FP31	Phenomenology
Dr. T.C. Kraan	01/1996 - 04/2000	FOM 94MF14	QFT
Dr. J.A.H. Keurentjes	09/1996 - 09/2000)	UL	QFT/Strings
Dr. R.C.W. van Gulik[2]	05/1997 - 09/2001	UL/NIKHEF	Phenomenology/Exp
D. Nogradi[3]	since 12/2000	UL	QFT/Strings

[1)] J. Schweizer, returned to home-University, Bern, Schwitzerland. [2)] R. van Gulik, first and last year in Leiden, otherwise at NIKHEF and CERN. His output is not reported here, except for date and title of thesis.
[3)] D. Nogradi, is on unpaid leave from Oct 2001 for 9 months, to follow the Tripos III course at DAMTP, Cambridge, UK.

Ph.D. degrees awarded in Leiden 1998-2001.

1. A.P. Chapovsky, *Instability and radiative corrections in pair production of W-bosons*, 23 september 1999, Univ. Leiden, promotor: Prof. Dr. F.A. Berends, co-promotor: Dr. W.J.P. Beenakker.
2. T.C. Kraan, *Periodic Instantons and Monopoles*, Univ. Leiden, 30 March 2000. Promotor: Prof. Dr. P.J. van Baal.
3. J.A.H. Keurentjes, *New Vacua for Yang-Mills Theory on a 3-torus*, Univ. Leiden, 29 June 2000. Promotor Prof. Dr. P.J. van Baal, co-promotor Prof. Dr. J. de Boer.
4. R.C.W. van Gulik, *Resonance Production in Two-Photon Collisions*, Univ. Leiden, 22 November 2001. Promotores: Prof. Dr. F. A. Berends and Prof. Dr. F.L. Linde.

Relevant developments at the university

In Leiden some important changes in the staff will occur. Prof. F.A. Berends will retire at the end of 2003 and an important shift of research interests will be made with the appointment of Prof. A. Achúcarro to include active research in the field of theoretical cosmology and astroparticle physics. At present she is secretary of COSLAB, an ESF programme to support studies of cosmology in the laboratory. A few of her publications over the last 5 years are included under items 92-97 at the end of the Leiden publication list in part II. She will start 1 May 2002 and will be working with a postdoc in the programme FP31 (see section 2).

Specific research topics, 1998-2001.

The research topics in the Ht-L working group for this period fall under the themes 'Phenomenology' and 'Quantum field theory'. It also included 'Quantum gravity and string theory', in particular in the period that Jan de Boer was in Leiden on a FOM-springplank position.

A.4 University Nijmegen (KUN): FOM-N-01

staff	date	emplyed by	topic
Dr. W. Beenakker	from 1/2001	FOM FP31/KUN	Field theory, rad. corr.
Prof. Dr. R. Kleiss		KUN	field theory, MC, multijets
Dr. Th. Rijken		KUN	Baryon-Baryon interactions
Prof. Dr. C. Dullemond		emeritus	Field theory, quantum mechanics
Prof. Dr. J. de Swart		emeritus	Nucleon-Nucleon interactions
visitors			
J. Nagata	up to 07/1998	Min. of Educ., Japan	phase-shift analysis
C. Makamoto	04/1999 - 03/2000	Min. of Educ., Japan	hybrid quark models
R. Bryan	06/2000-07/2000		
	and 10/2001-12/2001	Texas A&M	scalar mesons
Ph.D. students			
A. van Hameren	up to 01/2001	FOM FP31	numerical methods
C. Dams	from 10/2000	FOM FP31	Unstable particle collisions
H. Polinder	from 04/1999	KUN	Kaon-Nucleon models
P. Draggiotis	from 08/1998	KUN	QCD multijet production

Ph.D. degrees awarded in Nijmegen (KUN), 1998-2001.

1. A.F.W. van Hameren, *Loaded dice in Monte Carlo: importance sampling in phase space integration and probability distributions for discrepancies.*, Jan 2001. 160pp. Advisor: Prof. dr. R.H.P. Kleiss. e-Print Archive: hep-ph/0101094

2. M.C.M. rentmeester, *Applied Nucleon-Nucleon Partial-wave Analyses*, 21 May 2001. Advisor: Prof. dr. ir. J.J. de Swart

3. P. den Haan, *Aspects of QED renormalization in anti-de Sitter space*, 3 June 2001. Advisor: Prof. dr. C. Dullemond

Relevant developments at the university

In 2000, the EU program *Particle Physics Phenomenology at High Energy Colliders* was awarded, starting in August 2000 with a duration of 48 months. In 2001, Dr. W. Beenakker joined the group as UD with support from FOM programme FP31.

Specific research topics, 1998-2001.

The research topics in the Hth-N working group fall under the themes 'Phenomenology' and 'Quantum field theory'. Specifically we mention

- Discrepancy distributions: in numerical (Monte-Varlo or quasi-Monte Carlo) integration the *discrepancy, i.e.* the nonuniformity of the point set used governs the accuracy of the method. We have applied techniques from quantum field theory to compute the distribution of discrepancies for random point sets. This will enable a valid assessment of the quality of quasi-random point sets to be used in integration.

- Phase-space Monte Carlo algorithms: a set of MC algorithms (`SARGE`) was developed to model accurately the phase-space distribution of QCD antennae, thereby allowing the MC calculation of multijet production at high-energy colliders to be speeded up by a large factor.
- Multijet QCD: a program was developed that allows the computation of multijet production (up to at least 8 jets) in hadron collisions. This will be used for QCD studies and background studies at the LHC.
- Zero-dimensional field theories: these serve as both a pedagogical paradigm and as an approximation (static ultralocal limit) to realistic field theories. We have studied the validity of perturbation theory as a function of the complex values of the coupling constants, explicit solutions, and *recursive models* in which, for instance, higher-order corrections to certain amplitudes vanish beyond the one-loop order.

A.5 Universiteit Utrecht (UU): FOM-U-01

Staff	appointment dates	employed by	topic
prof. dr. B. de Wit		UU	
prof. dr. G. 't Hooft		UU	
prof. dr. J.A. Tjon		UU	
prof.dr. E.P. Verlinde	till 10/1999	UU	
dr. S. Vandoren	from 9/2001	UU	
dr. R. Loll	from 9/2001	UU	
dr. N. Obers	1/7/2000 - 1/4/2002	FOM springplank	
Postdocs	**appointment dates**	**employed by**	**topic**
dr. V. Shevchenko	1/07/2001-1/7/2003	FOM FP31	
dr. S. Stanciu	1/10/1999-1/10/2001	FOM FP31	D-branes
dr. J. Barbon	1998-1999	NWO	
dr. D. Berman	1998-2000	EU	M-theory 5-brane
dr. G. Cardoso	1997-2000	EU/UU	supergravity/string theory
dr. M. O'Loughlin	1998-2000	NWO	
dr. Y. Lozano	1998-1999	UU	
dr. S. Massar	1997-1998	UU	quantum information theory
dr. H.J. Matschull	1996-1998	UU/EU	3-dim gravity
dr. M.K. Parikh	1998-2001	NWO/UU	
dr. K. Skenderis	1998-1999	NWO	
dr. S.N. Solodukhin	1998-2000	UU	
dr. A.E.M. v.d. Ven	1998-2000	UU	
dr. H. Anastopoulos	2001-2003	EU	Quantum gravity
dr. G. Arcioni	2001-2003	UU	
dr. G. Bonelli	1999-2001	uu/NWO	branes/gravity
dr. A.M. Boyarsky	1999-2001	UU/NWO	branes/gravity
dr. B. Körs	2001-2003	UU/NWO	
dr. J.F. Morales Morera	2000-2002	EU	
dr. H. Samtleben	2001-2003	UU/NWO	
dr. M.M. Taylor-Robinson	2001-2003	UU/NWO	
dr. U. Theis	2001-2002	DFG	
dr. M. Trigiante	2000-2003	EU	D-branes
dr. S. de Haro	2001 (6 mo)	UU/NWO	

Ph.D. students	appointment dates	employed by	topic
drs. G.T.J. Zwart	1995-1999	FOM Hth-U	extended objects in string th.
drs. B.J.K. Kleijn	1/9/1994 - 1/9/1998	FOM Hth-U	supergravity
drs. V. Pascalutsa	1/9/1994 - 1/9/1998	FOM Hth-U	πN interaction
drs. G.A.P.T. Aarts	1/10/1995 - 1/10/1999	FOM FP31	baryogenesis
drs. J. Weda	1/9/1999 - 1/9/2003	FOM FP31	confinement in mesons
drs. J. Käppeli	1/4/1999 - 1/4/2003	FOM FP31	supersymmetry
drs. M. Welling	1993-1997	UU	quantum gravity
drs. C.M. Hofman	1996-2000	FOM MF-U-a	duality
drs. M. Holman	1/11/1999 - 1/11/2003	FOM Hth-U	
drs. I. Herger	1998-2001	EU/UU/NWO	supergravity and AdS/CFT
drs. I.L. Savonije	1998-2002	NWO	holography/cosmology
drs. B.J.W. van Tent	1997-2002	UU/NWO	cosmology
drs S. de Haro	1997-2001	UU/NWO	Black holes
drs. Z. Kadar	2001-2005	UU/NWO	
drs. S. Nobbenhuis	2001-2005	UU	

Ph.D. degrees awarded in Utrecht (UU), 1998-2001.

1. Kleijn, B.J.K.: New couplings in $N = 2$ supergravity. Promotor: B. de Wit. Utrecht, May 25, 1998.
2. Pascalutsa, V.: Covariant description of pion-nucleon dynamics. Promotor: prof.dr. J.A. Tjon. Utrecht, October 19, 1998.
3. Peeters, K.: Geometrical aspects of supersymmetry. Spinning particles, string dualities and the eleven-dimensional supermembrane. Promotor: B. de Wit. Utrecht, June 3, 1998.
4. Welling, M.: Classical and quantum gravity in 2+1 Dimensions. Promotor: G. 't Hooft. Utrecht, January 19,1998.
5. Aarts, G.A.P.T.: *Dynamics in equilibrium and nonequilibrium quantum field theory*, Promotor: prof.dr. J. Smit. Utrecht, October 4, 1999.
6. Zwart, G.T.J.: *String perspectives on gauge theories.* Promotor: prof.dr. E.P. Verlinde, Utrecht, November 29, 1999.
7. Hofman, C.M.: *Strings, Matrices, and Noncommutative Gauge Theory.* Promotor: prof. dr. E.P. Verlinde, Utrecht, September 19. 2000.
8. Haro Ollé, S. de: *Quantum gravity and the holographic principle (type I).* Advisor: prof. dr. G. 't Hooft, Utrecht, June 18. 2001.

Some developments at the university

The theoretical high-energy physics activities are carried out in the context of the program *Quantum Gravity, Strings and Supersymmetry* of the Spinoza Institute and the program *Quantum Gravity, Strings and Elementary Particles* of the Institute for Theoretical Physics. Both Institutes belong to the Department of Physics and Astronomy of Utrecht University.

Specific research topics, 1998-2001.

The research topics in the FOM program Fundamental Interactions cover all three themes 'Quantum gravity and string theory', 'Quantum field theory' and 'Phenomenology'.

A.6 Vrije Universiteit Amsterdam (VUA): FOM-V-01

Staff	dates	employer	topic
Prof. Dr. P.J. Mulders	since 01/01/1998	VUA	
Dr. B.L.G. Bakker		VUA	
Dr. D. Boer	since 01/07/2001	KNAW	
Postdocs/visitors	**dates**	**employer**	**topic**
Dr. A. Metz	01/09/2000-01/12/2001	EU-IHP	Chiral symmetry and
	01/12/2001-01/07/2002	FOM FP31	fragmentation functions
Dr. R. Kundu	01/10/2000-01/12/2001	FOM FP31	Lightcone field theory
Dr. M. Boglione	15/10/1997-15/02/1999	EU-TMR	Deep inelastic scattering
	16/02/1999-01/07/2000	FOM 98PR1714	and azimuthal asymmetries
Prof. Dr. E. Leader	1998 - 2002	FOM 98PR1714	Deep inelastic scattering
Dr. B. Krippa	01/03/1999-31/05/2001	FOM 98PR1714	Chiral symmetry
		Russian Academy	
Dr. J.G. Milhano	01/10/2001-01/10/2003	VUA	Low x/Phases of QCD
Ph.D. students	**dates**	**employer**	**topic**
Drs. N. Schoonderwoerd	15/12/1995-01/03/1999	FOM Hth	Lightcone field theory
Drs. M. van Iersel	01/08/1999-01/08/2003	FOM FP31	Lightcone field theory
Drs. A. Bacchetta	01/11/1998-01/11/2002	FOM 98PR1714	Transverse spin polarization
Drs. A. Henneman	01/10/1996-01/08/2001	VUA	Evolution and transverse momentum
Drs. J. Rodrigues	1994 - 1998	external[1)]	Gluon correlations in DIS
Drs. F. Pijlman	01/11/2001-01/11/2005	VUA	DIS/intrinsic transverse momentum
Drs. H. Warringa	01/12/2001-01/12/2005	VUA/USF	Phases of QCD

[1)] supported by the University of Lisbon and PRAXIS programme.

Ph.D. degrees awarded in Amsterdam (VUA), 1998-2001.

1. D. Boer, *Azimuthal asymmetries in hard scattering processes*, 15 Sep 1998, Vrije Universiteit. Promotor: Prof. dr. P.J.G. Mulders.

2. N.C. Schoonderwoerd, *Light front hamiltonian field theory; towards a relativistic description of bound states*, 14 Jan. 1999, Vrije Universiteit. Promotor: Prof. dr. P.J.G. Mulders; copromotor: Dr. B.L.G. Bakker.

3. J. Rodrigues, *Modelling quark and gluon correlation functions*, 16 Oct. 2001, Vrije Universiteit. Promotor: Prof. dr. P.J.G. Mulders.

Relevant developments at the university

The theoretical high-energy physics activities at the VU are part of the Theoretical Physics department within the Division of Physics and Astronomy. In 1999 the university has approved a proposal of Mulders to initiate studies on *Phases of QCD*. This program has started recently and is performed in collaboration with D. Boer, who has been appointed as a KNAW fellow in 2001.

Specific research topics, 1998-2001.

In VU theory group working in particle physics, a number of topics are addressed belonging to themes 'Quantum field theory' and 'Phenomenology'.

- Deep inelastic scattering processes. The emphasis of the group is on the inclusion of effects of parton intrinsic transverse momentum. This gives rise to azimuthal asymmetries, in particular in polarized processes. For this a detailed analysis of quark distribution and fragmentation functions in polarized hadrons has been made.

- Lightcone quantization. Quantization in the front form is in principle equivalent to instant form quantization. In practice many details remain to be studied. For QCD front form quantization may be a promising route, because the wave functions in the hamiltonian formulation can be directly connected to the quark distribution functions in deep inelastic scattering.
- The study of phases in QCD, that may have played a role in early-universe physics, is a research line that has just started in 2001.

B Publications

B.1 Publications FOM-A-01

1. G. Aarts and J. Smit, *Classical Approximation for Time Dependent Quantum Field Theory: Diagrammatic Analysis for Hot Scalar Fields*, Nucl. Phys. B511 (1998) pp. 451-478.
2. F.A. Bais, N.M. Muller, *Topological field theory and the quantum double of SU(2)*, Nucl. Phys. B530 (1998) 349-400.
3. F.A. Bais, B.J. Schroers, *Quantization of monopoles with nonAbelian magnetic charge*, Nucl. Phys. B512 (1998) 250-294.
4. F.A. Bais, et al., (ed), *Strings*, Proceedings International Conference "Strings'97", Amsterdam, the Netherlands, June 16-21, 1997, Nucl. Phys. B, Proc. Suppl. 68 (1998) 397 .
5. S. Bilke, Z. Burda, A. Krzywicki, B. Petersson, G. Thorleifsson, *4-D Simplicial Quantum Gravity unteracting with Gauge Matter Fields*, Phys.Lett. 418B (1998) 266-272.
6. S. Bilke, Z. Burda, A. Krzywicki, B. Petersson, G. Thorleifsson, *4-D Simplicial Quantum Gravity: Matter Fields and the corresponding effective action*, Phys.Lett. 432B (1998) 279-286.
7. R. Dijkgraaf, H. Verlinde and E. Verlinde, *Notes On Matrix And Micro Strings*, Nucl. Phys. Proc. Suppl. 67 (1998) 225-250 and Nucl. Phys. Proc. Suppl. 68 (1998) 28-54.
8. *Les Houches Lectures on Fields, Strings and Duality,* in "Quantum Symmetries," Les Houches LXIV, 1995, Eds. A. Connes, K. Gawedzki, J. Zinn-Justin Elsevier, Amsterdam, 1998, 3–147, hep-th/9703136.
9. L.P.A. Haakman, O.V. Kancheli and J.H. Koch, *The BFKL Pomeron with running coupling constant: how much of its hard nature survives?*, Nucl. Phys. **B518** (1998) 275-302.
10. L.P.A. Haakman, A.B. Kaidalov and J.H. Koch, *Charm production in deep inelastic and diffractive scattering*, Eur. Phys. Journal C1 (1998) 547-561.
11. C.M. Hofman and J.-S. Park, *Monads, Strings, M-Theory*, Nucl. Phys. B 520 (1998) 229-260.
12. J.H. Koch, H.R. Mall and S. Lenz, *Stochastic methods for zero energy quantum scattering*, Comp. Phys. Communications 108 (1998) 115-146.
13. T.H. Koornwinder, F.A. Bais, N. Muller, *Tensor product representations of the quantum double of a compact group*, Commun. Math. Phys. 198 (1998) 157-186.
14. B.J. Nauta and Ch.G. van Weert, *Time Dimensional Reduction in Thermal Field Theory*, Proceedings of the 5th International Workshop on Thermal Field Theories and Their Applications, U. Heinz (ed.), hep-ph/9811469, 1998.
15. B.J. Schroers, F.A. Bais, *Charge sectors and S duality in* $SU(3)$ *Yang-Mills theory with non-abelian unbroken gauge group*, Nucl. Phys. B535 (1998) 197-218.
16. J. Smit, *Classical Approximation for Time Dependent Quantum Field Theory: Diagrammatic Analysis for Hot Scalar Fields, Proceedings of the conference Strong and Electroweak Matter*, F. Csikor and Z. Fodor eds. (World Scientific 1998) pp. 284-288.
17. J. Smit, *Real Time Simulations and the Electroweak Phase Transition*, Proceedings of Lattice 97: 15th International Symposium on Lattice Field Theory, Nucl. Phys. (Proc. Suppl.) 63 (1998) pp. 89-94.

18. W.H. Tang and J. Smit, *Numerical Study of Plasmon Properties in the SU(2) Higgs Model*, Nucl. Phys. B510 (1998) pp. 401-420.

19. H. Verlinde, *Five-branes and Matrix Strings*, Nucl.Phys.Proc.Suppl. 62 (1998) 348-362.

20. G.A.P.T. Aarts and J. Smit, *Real time dynamics with fermions on a lattice*, Nucl. Phys. B555 (1999) 355-394.

21. G.A.P.T. Aarts and J. Smit, *Dynamics of fermions and inhomogeneous Bose fields on a spacetime lattice*, in: Proc. of Strong and Electroweak Matter '98, NORDITA and Niels Bohr Institute, Copenhagen, Denmark, December 2-5, 1998, World Scientific Publ., Singapore (1999) 168-172.

22. M. Berkooz and H.L. Verlinde, *Matrix Theory, AdS/CFT and Higgs-Coulomb Equivalence*, hep-th/9907100, JHEP 9911 (1999) 037.

23. S. Bilke and G. Thorleifsson, *Simulating four-dimensional simplicial gravity using degenerate triangulations*, Phys. Rev. D59 (1999) 124008-124012.

24. S. Bilke and G. Thorleifsson, *Simulating 4D simplicial gravity including degenerate triangulations*, Nucl. Phys. Proc. Suppl. 73 (1999) 801-803.

25. S. Bilke, Z. Burda, A. Krzywicki, B. Petersson, K. Petrov, J. Tabaczek and G. Thorleifsson, *The strong-coupling expansion in simplicial quantum gravity*, Nucl. Phys. Proc. Suppl. 73 (1999) 798-800.

26. R. Dijkgraaf, *Fields, strings, matrices and symmetric products*, in: Proceedings of the Conference 'Moduli of curves and abelian varieties', Vieweg, Braunschweig, Duitsland, 1999, pp. 151-199.

27. R. Dijkgraaf, *Instanton strings and hyper-Kähler geometry*, Nuclear Phys. B 543 (1999) 545-571.

28. S.B. Giddings, F.H. Hacquebord and H.L. Verlinde, *High Energy Scattering and D-pair Production in Matrix String Theory*, Nucl.Phys. B537 (1999) 260-296.

29. F.H. Hacquebord, *Symmetries and Interactions in Matrix String Theory*, promotor prof.dr. H.L. Verlinde, Universiteit van Amsterdam, Amsterdam, September 22, 1999, 120p.

30. C. Hofman, J.-S. Park, *Sigma Models for Bundles on Calabi-Yau: A Proposal for Matrix String Compactifications*, Nucl.Phys. B561 (1999) 125-156.

31. T. H. Koornwinder, B. J. Schroers, J. K. Slingerland and F. A. Bais, *Fourier transform and the Verlinde formula for the quantum double of a finite group*, [math.qa/9904029], J. Phys. A: math.gen. 32 (1999) 8539-8549.

32. J.-S. Park, *Cohomological Field Theories on Complex Manifolds*, promotor prof.dr. H.L. Verlinde, Universiteit van Amsterdam, Amsterdam, November 23, 1999, 165p.

33. J. Smit, *Sphaleron rate at high temperature in (1+1) dimensions*, Nucl. Phys. Proc. Suppl. 73 (1999) 665-667.

34. W.H. Tang and J. Smit, *High-temperature behavior of the Chern-Simons diffusion rate in the 1+1 dimensional abelian Higgs model*, Nucl. Phys. B540 (1999) 437-456.

35. M.A. Vazquez-Mozo, *A note on supersymmetric Yang-Mills thermodynamics*, (hep-th/9905030), Phys. Rev. D60 (1999) 106010-106018.

36. M. de Wild Propitius and F.A. Bais, *Discrete gauge theories*, in: Particles and Fields. G.W. Semenoff ed., (CRM Series in Math. Physics) Springer Verlag, Berlin, 1998, 353-440.

37. G. Aarts, B. J. Nauta, and Ch. G. van Weert, *Divergences in classical theories at non-zero temperature*, Phys. Rev. D61 (2000) 105002-105027.

38. G. Aarts and J. Smit, *Particle Production and Effective Thermalization in Inhomogeneous Mean Field Theory*, Phys.Rev. D61 (2000) 025002-105027.

39. G. Aarts and J. Smit, *Real-Time Dynamics in the (1+1)-D Abelian Higgs Model with Fermions*, in: proceedings of the 17th International Symposium on Lattice Field Theory (LATTICE 99), Pisa, Italy, 29 June - 3 July 1999, Nucl.Phys.Proc.Suppl. 83 (2000) 586-588.

40. G. Arcioni, J.L.F. Barbón, J. Gomis and M.A. Vazquez-Mozo, *On the stringy nature of winding states in noncommutative thermal field theories*, hep-th/0004080, JHEP 0006 (2000) 038.

41. G. Arcioni and M.A. Vazquez-Mozo, *Thermal effects in perturbative noncommutative gauge theories*, hep-th/9912140, JHEP 0001 (2000) 28.

42. A. Arrizabalaga, B. J. Nauta, and Ch. G. van Weert, *Transversality of logarithmic divergences in the classical SU(N) self-energy*, Phys. Lett. B491 (2000) 214-218.

43. J. de Boer, *String Theory on AdS Backgrounds*, Proceedings of Strings 1999, Potsdam, Germany, Class.Quant.Grav. 17 (2000) 1027-1034.

44. J. de Boer, E. Verlinde, H.L. Verlinde, *On the Holographic Renormalization Group*, JHEP 0008 (2000) 003.

45. J. de Boer, J. Evslin, M.B. Halpern, J.E. Wang, *New duality Transformations in Orbifold Theory*, Int.J.Mod.Phys. A15 (2000) 1297-1344.

46. J. de Boer, *String Theory on AdS Spaces*, in: Proceedings of Workshop in Superstring and M-theory, October 27-29, 2000, Kyoto, Japan.

47. R. Dijkgraaf, *On The D1-D5 Conformal Field Theory*, Class. Quant. Grav. **17**, 1035 (2000).

48. A. Feinstein and M.A. Vazquez-Mozo, *M-theory resolution of four-dimensional cosmological singularities via U-duality*, hep-th/9906006, Nucl. Phys. B568 (2000) 405-420.

49. A. Feinstein, K.E. Kunze and M.A. Vazquez-Mozo, *Initial conditions and the structure of the singularity in wave collision induced pre-big-bang cosmology*, hep-th/0002070, Classical and Quantum Gravity 17 (2000) 3599-3616.

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B.6 Publications FOM-V-01

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