# Quantum Field Theory

Quantum field theory (QFT) is the „language“ describing the fundamental physics in the relativistic microcosmos, notably the elementary particles. In a continuous endeavor, the quantum field theory group in Göttingen (previously led by Max Planck medalists Gerhart Lüders, Hans-Jürgen Borchers, and Detlev Buchholz) pursues a mathematical approach in which the strong internal constraints imposed by the interplay between the principles of relativity, Einstein causality, and the stability of quantum systems are explored. It turns out that notions like „particle“, „charge“, and their fundamental interactions are far more subtle in QFT than in the more familiar setting of quantum mechanics. A careful analysis of these structures leads to insights that bear fruit in many applications.

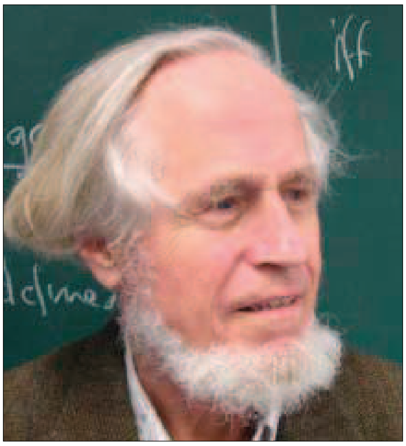
## Charges and symmetries

Apart from the electric charge, particle physicists have become familiar with many different charges, including „flavor“ and „color“ of leptons and quarks. The traditional understanding of charge quantum numbers as characteristic eigenvalues in representations of internal symmetry groups involves unobservable entities. An intrinsic characterization in terms of observable data has confirmed this picture, but it has also revealed its limitations, e.g. in the presence of long-range forces. Especially in model theories in less than three space dimensions, the association of charges with symmetry groups cannot be maintained, and a world of new types of „quantum charges“ has been discovered, including the fascinating theory of generalized symmetries, which occur in real physics in the guise of critical behavior of statistical systems confined to surfaces.

## Particles

The fundamental observables in relativistic quantum physics are neutral fields. Particles arise as excitations in certain states in which these fields can be measured. As such they may possess properties depending on the state. For instance, their mass can be temperature dependent, if it can be sharply defined at all. Defining the mass of a particle in interaction is not an easy task. In scattering theory, one can wait until the particle is far away from all other particles, and hence its mass can be defined as for non-interacting particles. This is clearly not possible if the particle is confined, as for quarks, or if it cannot be separated from a surrounding „photon cloud“ due to its electric charge and the long-range nature of the electromagnetic interaction, or if it moves in a thermal environment. The conceptual problems with the notion of „particle“ were attacked in Göttingen, and led to several new analytic tools allowing to compute their properties.

Gerhart Lüders



Hans-Jürgen Borchers

Detlev Buchholz

## Hot matter

The interaction with a thermal background leads to a drastic change of particle behavior. They no longer arise as asymptotically stable entities, but rather as excitations of the background that dissipate less rapidly than all other perturbations. In large scale systems, thermal equilibrium can only exist locally. The question arises, then, how a local temperature can be defined in a relativistic quantum theory. These and related questions were addressed in our group, and new methods were developed to define and compute local temperatures within the microscopic theory and to derive transport equations for macroscopic observables such as particle densities.

## Conformal symmetry

At very high energies, nature seems to exhibit a symmetry which goes beyond relativistic invariance: conformal symmetry. It is a very restrictive property that can be exploited both for the classification and for the construction of quantum field theory models. In two dimensions of spacetime, we have initiated a general theory how a given model can be extended, and how the presence of boundaries change the admissible states of a conformal quantum field theory. A program of constructing such theories in four dimensions of spacetime is presently pursued.

## Construction

The rigorous construction of realistic models of interacting quantum field theory is a difficult task due to the highly singular nature of the fields and the strong quantum fluctuations of the vacuum state. In two dimensions of spacetime the situation is better, and large classes of models have been constructed. A variety of new schemes for construction, that build on the genuine quantum features rather than classical field equations, were developped in our group.

## The challenge of Gravity

The consistent incorporation of the principles underlying the classical theory of Gravity and the principles of Quantum Theory into a future Theory of Quantum Gravity is one of the great challenges in fundamental physics. Our group pursues a systematic first step towards this goal: the study of the interaction between quantum fields of matter and classical gravitational fields. Recent progress in the understanding of the principle of General Relativity allows promising new applications, such as the systematic investigation of quantum matter in the neighborhood of black holes.

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### Karl-Henning Rehren

Karl-Henning Rehren, was born in 1956 in Celle. He studied physics and astronomy in Göttingen, Heidelberg and Freiburg im Breisgau, where he received his PhD 1984 under the supervision of Klaus Pohlmeyer. He had a scholarship semester at the École Normale Supérieure Paris, PostDoc positions at the Freie Universität Berlin and in Utrecht (Netherlands), and was an assistent at Hamburg University. He is Hochschuldozent (since 1997) and Professor (since 2002) at the Institute for Theoretical Physics, Göttingen University. Presently, he is Chairman of the Fachverband „Theoretische und Mathematische Grundlagen der Physik" in the Deutsche Physikalische Gesellschaft, member of the Graduiertenkolleg 1493 „Mathematical Methods in Modern Quantum Physics", and Principal Investigator in the Courant Research Centre „Higher Order Structures in Mathematics".