Part I
Reminiscences: Rolf Hagedorn *and* Relativistic Heavy Ion Research
edited by Johann Rafelski

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The year 1964/1965 saw the rise of several new ideas which have shaped fundamental physics for the past 50 years. Quarks and the Higgs particle were invented, and the limiting Hagedorn temperature T_{H} , the melting point of hadrons, was recognized. Of course back in Fall 1964—Spring 1965, if someone were asked how these new ideas could turn into the standard model of particle physics; or lead to the discovery of a new phase of matter: quark-gluon plasma—the response would have been stupendous silence.

The simple question—why cannot quarks be put on open display?—demonstrates that there is more to understanding the laws of physics than the classification of the standard model particle zoo and the measurement of its many parameters. The manifestation of all laws of physics and especially of strong interactions require incorporation of the response of the vacuum state, the modern day quantum and relativity compatible 'æther'. This is a shift in the paradigm, and thus we have to work much harder at explaining the advance in our understanding that is being made.

Rolf Hagedorn was the scientist whose dedicated, determined personal commitment formed the deep roots of this novel area of physics. I can say with certainty that in Fall 1964 he had no clue what would happen to his T_{H} in the next 20 years. This book, especially Part I, shows how from a humble beginning a path to the new paradigm of strong interactions emerged, as well as how this research program found its way onto the menu of major laboratories, in particular CERN, where the quark-gluon plasma first became experimental reality.

Rolf Hagedorn's work in the field of hot hadronic matter dominated this research field during the first 15 years: his talks and publications often gave the decisive turn to events. In order to fully appreciate the physics of *Melting Hadrons, Boiling Quarks*, one must explore the thinking of this man. It is appropriate to ask his former collaborators and those involved in the research program today to make contributions describing past events and/or their present status. In doing this one is naturally led to invite each contributor to write about Hagedorn, both as a scientist and an extraordinary human being.

Fifteen essays by 17 authors offer reflections on Rolf Hagedorn, his science, and the growth of Hagedorn's ideas to the current quark-gluon plasma experimental program. These contributions show the only place where Hagedorn worked, CERN, from its creation to the present day, as seen through eyes of Hagedorn and his contemporaries—it so happens that Hagedorn was one of the first CERN employees. Some contributions are drawn from material presented on Hagedorn's 75th birthday—updated and refreshed by the authors, with the exception of the essay by Maurice Jacob which is printed posthumously; hence I adapted it to the current format.

I believe that these first 125 pages give an accurate picture of how Hagedorn's journey in science brought CERN to the opportunity to pursue the quark-gluon plasma discovery. Each contribution is the work of its author: I did not act as a referee but as a friend and colleague, guiding when possible the author to what I did not yet see in the contents. But how it is said is entirely the doing of each contributor—in that way I believe a sincere, personal and complemental account has emerged. I thank all for their kind and understanding cooperation.

Chapter 1
Spotlight on Rolf Hagedorn

Johann Rafelski

Abstract I describe several events that characterize my work with and my personal relationship with Rolf Hagedorn himself, closing with biographical remarks.

1.1 Working with Hagedorn

Meeting Hagedorn

I had the privilege of interacting closely with Rolf Hagedorn during the last 25 years of his life. The pivotal role that Hagedorn played in my development was as my teacher of relativistic statistical and thermal physics, and of particle production. The timing of our collaboration was singular due to the coincidence with the scientific rise of quark-gluon plasma research. Though we published only about half-a-dozen papers together, we worked together on many of publications that were later published by us independently, an approach consistent with the unique personality of Hagedorn that will emerge from these pages. In my work, I could build on the personal strengths and scientific achievement of Hagedorn in helping to develop a new research area, the formation and observation of quark-gluon plasma.

I first met Rolf Hagedorn, Fig. 1.1, in the winter 1975/1976 when I attended his Colloquium on the Statistical Bootstrap Model presented at the University Frankfurt. Hagedorn offered a fascinating description of thermal multiparticle physics, and after his talk he found a way to answer all questions. At that time I knew little about subjects such as the Statistical Bootstrap Model, or relativistic statistical mechanics, or about the experimental data in which Hagedorn was so deeply interested. In fact I even lacked a thorough understanding of thermal physics, not unusual in the particle or the nuclear context in the early 1970s.

After the talk I privately asked Hagedorn a few naive questions. Hagedorn took everything seriously, and gave clear explanations to the questions which could be answered. At that time I was working on the quark structure of hadrons and it

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Fig. 1.1 Rolf Hagedorn (*center*), with Johann Rafelski June 30, 1994. *CREDIT: CERN Photo 1994-06-064-024*

seemed to me that the work of Hagedorn should connect with this topic, as well as with another topic shaping my scientific background at the time, the field of heavy ion collisions. It became clear to me that I could learn what I needed from Hagedorn. I asked if I could visit him at CERN and he suggested I consider a short-term position application. I arrived as a CERN-Fellow on September 1, 1977.

From our first meeting, my personal impression was that Hagedorn was a modest, determined person. Important for the success of our collaboration was that he was remarkably structured in organizing his work and in presenting the outcome of his research: Hagedorn did not need to make a draft in order to create an immaculate write-up of a manuscript. All his work, personal or professional, was from the first to the last word clear and presentable. His letters rarely had corrections, and if so, he made these visible and readable—to show that he changed his mind. In seminars his questions were precise and thus could be answered. All this went along with the perfect arrangement of his desk and the office in general; everything had a place, as can be seen in Fig. 1.2.

Our collaboration was in the first years that of a teacher and a student: Rolf Hagedorn presented his ideas and theoretical work slowly, repeating details until, in his eyes, I understood everything. Sometimes we sat in his office for hours, from the morning till evening. I occasionally worried that I was wasting too much of his time, and tried out other collaborations. But I always returned, attracted to both the person and the subject. I can say that Hagedorn taught me in a year what took him nearly 20 years to discover. This has been a gigantic advantage that still marks my abilities to this day.

I think our different career paths, different fields of expertise, and different approaches to physics, meshed in a special way: for example when Hagedorn began his formal physics education at Göttingen his age was the same as mine upon my arrival at CERN. We were curious about each other's research, which was complementary. Hagedorn was a natural teacher looking for a student, and I wanted to learn what Hagedorn knew. Hagedorn liked a structured classroom—as we shall

Fig. 1.2 Rolf Hagedorn at his office desk, 1978. *Photo: Johann Rafelski*

see, he even attended a class on retirement; I like jumps into deep water—leaving me no other choice but to swim. As I 'swam' along with Hagedorn, he strongly influenced my development as a physicist. Meeting him helped me in my choice of research field, and I worked for many years in the field that he pioneered.

A Short Story About Hagedorn Temperature

On 3 February 1978, Rolf Hagedorn handed me a copy of his unpublished manuscript, "Thermodynamics of distinguishable particles". This original had a big red dot-mark, showing it was the original, not to be lost, with the number "0" meaning less than "1" (see below). Hagedorn kept just one red-marked copy and mentioned that another was in the CERN archives. He told me that I was to keep a copy to myself—a promise I can now break having found the document on the CERN Document Server (CDS). This was the initial unpublished paper proposing an exponential hadron mass-spectrum and the limiting (Hagedorn) temperature.

Discussing with me this first paper, see Chap. 19, on limiting temperature—CERN preprint TH-483 dated 12 October 1964 Hagedorn recollected: "After Léon van Hove (see Fig. 1.3) read the manuscript, he asked me to compute requirements for the hadron mass-spectrum. This led me to recognize that not every, even exponential, mass-spectrum produces limiting temperature." Hagedorn made it clear that did not like this ad-hoc fine-tuning. By October 27, 1964 Hagedorn concluded that his result was too model-dependent to publish and placed the justification for his decision in the CERN archives, see Chap. 18.

Fig. 1.3 Rolf Hagedorn (on *left*) in discussion with Léon van Hove (on *right*), December 1968. *Image credit: CERN Image 68-12-143*

The CERN-TH 520 preprint dated 24 January 1965, "Statistical Thermodynamics of Strong Interactions at High Energies"—marked with a big "1" in the Hagedorn collection is today the renowned "Hagedorn paper". It is relevant to recollect what dates on CERN-TH preprints meant: In those days, a hand-written manuscript was handed to Tania Fabergé, the Theory Division (TH) secretary, Fig. 1.4; it received a sequential TH-preprint number and the day's date, as recorded in the TH log-book.

During my days at CERN after 1977 a normal length paper sat in the typing queue in the TH office until it reappeared in my mailbox or I got it back from Marie-Noëlle Fontaine, see Fig. 1.4, with date and number clearly visible on the front page. Somewhere along the line a senior member of TH would look at the work. This was a mild internal refereeing that also helped a young fellow like me to meet senior division members. This is how I made new friends in the Theory Division including John Bell, Maurice Jacob, and Jacques Prentki. I do not mention here Rolf Hagedorn or Léon van Hove, both of whom I met before my arrival at CERN. It is quite possible that the interaction between van Hove and Hagedorn that caused the withdrawal of the '0' paper was just such an internal refereeing exercise.

Another point in this story is that between the CERN-TH date and the actual mailing out of the paper to publishers, and the distribution as a CERN preprint, perhaps 8 weeks had to pass. Hagedorn's article was received by Nuovo Cimento Supplemento on 12 March 1965, and the issue no. 2 of vol. III, 1st series (1965), was printed on 28 January 1966. This was an average delay for the journal.[1] Hagedorn's monumental work received, as I believe its first citation in an experimental *Physical Review Letters* submitted in March 1967 and printed in July 1967.

The contents of the paper '1' was widely available by means of CERN preprint distribution to most particle physics libraries in Spring 1965. Thus more than 2 years had passed between the report of the birth of Hagedorn limiting temperature, and someone distant noticing this new idea and the citation itself being visible. By

[1]I thank Tullio Basaglia of CERN library for careful log of the time line of publications published in NC Supplemento.

Fig. 1.4 *Top*: Tania Fabergé, *bottom* Marie-Noëlle Fontaine talking with Gilbert Lévrier at their CERN-TH desks, Fall 1978; *Photos: Johann Rafelski*

our contemporary measure, absence of a citation in the first 2 years means that Hagedorn's monumental invention of limiting temperature had 'impact' zero. Even so, within a decade, Hagedorn (limiting) temperature had become a household term in the physics community and the SBM paper was cited several hundred times.

Hot Nuclear Matter in the Statistical Bootstrap Model

After I settled at CERN in Fall 1977, we immediately turned to our joint project: Hagedorn remembered our Frankfurt discussions and resumed my education about particle production and the statistical bootstrap as if we had never been interrupted. I brought into the collaboration my know-how about heavy ion collisions, confinement, and quarks. Within a few weeks we saw the scope of the work that would emerge from our discussions in the coming years.

Our collaboration had clear objectives: to develop an understanding of both, the hot and dense baryon-rich hadronic matter, see Chap. 23, and to determine particle spectra emanating from the hot fireball of hadronic matter created in relativistic heavy ion collisions, see Chaps. 26 and 27. Considered after the fact, perhaps we should have established our priority by publishing on dissolving hadrons into quark matter in collisions of heavy ions a few weeks after we started. However, what we knew in Fall 1977 was not good enough for Hagedorn, who desired a fully consistent model, see Hagedorn's retrospective on our work in Sect. 25.4 on page 299 ff.

Hagedorn wanted a solid theoretical model of hot nuclear matter, fully consistent with all he knew about particle production, something the world could trust for years to come. Building such a 'good' model is an iterative, time-consuming process. We had to explore alternatives and needed to identify potential inconsistencies. Slowly we progressed towards a fully comprehensive SBM based model of hot nuclear matter. Looking back at those long sessions in the Winter of 1977/1978 I see a blackboard full of clean, exactly formed equations—and a sign instructing that no one should clean the board; Hagedorn expected we would resume next morning. One day I took a few pictures of Hagedorn in his office as is shown in Fig. 1.5.

As I learned from Hagedorn to recite by heart all the results of relativistic thermodynamics, days of work became weeks, and weeks became months, and the word about our effort spread ever wider. Our daily discussions helped the iterative

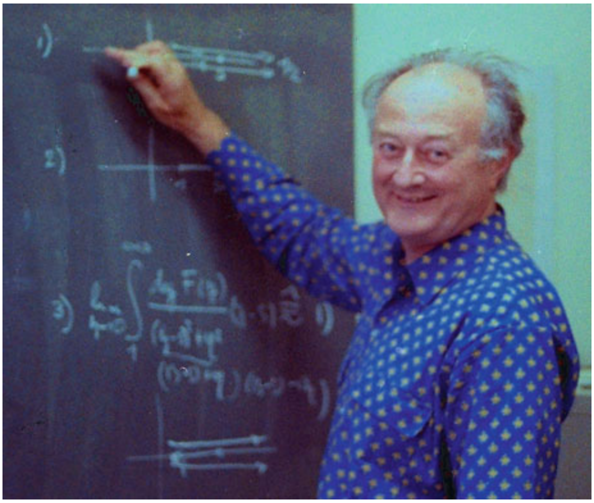

Fig. 1.5 Rolf Hagedorn at the blackboard Fall 1978. *Photo: Johann Rafelski*

discovery process. It was the arrival of István Montvay, see Chap. 5, that sped up the paper writing; he joined in our discussions, contributed many important insights, and was helpful in making us appreciate how much we knew and how important it was to share our insights with our colleagues. So by early Summer 1978 we started as a team of three the writing up of the SBM model of hot nuclear matter.

Our results were ready for presentation in late Summer 1978, and we made two extensive conference presentations of our effort. In mid-October 1978 Hagedorn presented at the Erice workshop, an event organized also to remember his 60th birthday by Helmut Satz and Luigi Sertorio,[2] while I presented in January 1979 at the Bormio series of Winter meetings, see Chap. 23. Given that many people tracked the widely distributed CERN preprints, and Hagedorn was a name that many followed, our results were soon well known. We made no effort to prepare a formal publication. 'Everybody' knew of our work; the meeting proceedings (often printed by an University Press e.g. the Bormio 1979 volume) and CERN preprints were just what the Internet provides today, a free flow of scientific information.

Higher Level Computer Language

When we started to convert our ideas into results that would lead to publications, one could imagine that this was the moment when a younger collaborator would carry the load of the work. In fact before my arrival at CERN I had plenty of practice working with teletype terminals (who still remembers these?), programming in Fortran, and drawing results by hand. It turned out that for Hagedorn this was ancient technology. Rolf Hagedorn enjoyed tremendously the moment, and was resolved to prove to me how much simpler and faster it was possible to make the required computations with SIGMA (System for Interactive Graphical and Mathematical Applications).

This was the computer language he had helped develop for use in direct interaction with the computer, working at its console, see Fig. 1.6, or by the time we worked together, at a remote terminal. Indeed, Hagedorn was able to complete the required calculations rapidly, and to obtain the graphic representation of our results on screen and to print these out practically ready for publication.

Development of a user-friendly computer interface, and of an easy-to-use higher level language was another pioneering idea that Hagedorn spearheaded at CERN. Arguably, this development at CERN by Hagedorn and a few collaborators (Carlo Vandoni and Juris Reinfelds in particular) of direct user-computer interactive approach, and user-oriented language, spearheaded in the CERN Computer Department the traditions which seeded the birth of the Internet at CERN 20 years later.

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[2] Proceedings *Hadron Matter at Extreme Energy Density* were edited by N. Cabibbo and L. Sertorio as Volume 2 in a new *Ettore Majorana International Science Series*, published by Plenum Press (New York 1980).

Fig. 1.6 Rolf Hagedorn, seen here working at CERN at a computer console in 1968, when the GAMMA (Graphically Aided Mathematical MAchine), a precursor to SIGMA computer language, he helped develop was launched; *Credit: CERN photo 68-12-141*

Relativistic Heavy Ion Collisions

In the 1970s the emerging European center for the new field of relativistic heavy ion collisions was GSI, the German Heavy Ion laboratory located between Frankfurt and Darmstadt in the village of Wixhausen, today part of suburban Darmstadt. In 1977 the experimental work was carried out in the US at the Lawrence Berkeley Laboratory's Bevalac, see Chaps. 12 and 13. GSI was the site where the experiments were prepared and data was processed, and many researchers called it home.

On the way to CERN in Spring and Summer 1977 I was able to spend some of my time at GSI. During this short period I made friends who were later important in developing the relativistic heavy ion program at CERN. Particularly relevant was meeting Rudolph Bock, who was the pre-eminent force for relativistic heavy ion physics in Europe. His experimental group worked at the Bevalac, many of these individual researchers would later shape the CERN research program, see Chap. 13.

Due to the prior meeting with Hagedorn that left such a deep mark, I recognized a scientific opportunity to merge my interest in quarks and heavy ion collisions with Hagedorn's statistical particle production model. The visit to GSI reinforced this viewpoint. By pursuing our collaborative goals Hagedorn and I 'discovered' theoretically the phase boundary to quark-gluon plasma (QGP) right before the relativistic heavy ion collision experimental program, see Chap. 25.

When Hagedorn and I started our collaboration, it was based on the intersection of our common capabilities and interests, without direct concern for a possible

CERN heavy ion experimental program which seemed to be set to happen at GSI or/and LBL. Seminars and corridor discussions spread the word of our effort. In particular, the cafeteria in the main CERN building has been and is a place where people come and go, and where stories are told. Our effort to capture the physics of hot nuclear matter in the perspective of particle production and the detailed understanding of its boundary with hot quark-gluon matter formation was soon known to many, as was our view of the relevance of our work to relativistic heavy ion collision physics.

We made an effort to let the world know what we were doing. Hagedorn, in charge of several lecture series at CERN, asked me to bring in a few people who could tell him and everyone interested about the potential for experiments with relativistic heavy ion collisions. This created the opportunity to speak in private to those directly interested in our work. We could see how these visiting experts react. I suggested inviting several experimentalists from GSI and LBL; among them was Hans Gutbrod, who soon found a lasting home at CERN, see Chap. 13.

In this line of thought, Maurice Jacob connected us with the CERN experimental groups working at the Intersecting Storage Rings (ISR), see Chap. 28. Bill Willis and many others were convinced that nuclear collisions within the ISR experimental program could provide access to new physics. This interest awakened CERN management to the new 'heavy ion' scientific opportunity, although at first the general community's reception was pretty frosty. A different way to achieve the same scientific goal was found, made possible by Herwig Schopper, by using SPS as a heavy ion machine, see Chap. 29. This approach was compatible with CERN pushing ahead into the LEP era, and preparing the technology and building the large underground tunnel that today houses the LHC.

In late 1979, while our heavy ion effort was going on, I moved from CERN to Frankfurt. Following tradition I was invited to present an inaugural lecture, which was scheduled for June 18, 1980. The translation of the German abstract I submitted reads: "**Quark Matter–Nuclear Matter:** The fusion of constituents of protons and neutrons—quarks—into quark matter is expected to form a new phase of nuclear matter. Based on our recent theoretical work this is expected to occur at temperature and density accessible to experimental study."

This lecture was a preliminary version of the presentation I would give in a few months at the Bielefeld workshop in August, and a few weeks later at the GSI-Laboratory, see Chap. 27. At this meeting for the first time a discussion of experimental signatures was a keynote topic and thus it has been since designated to be the first of the "Quark Matter" meeting series. My proposed strange particle signature of QGP was a major component of this presentation. In the following months and years I developed the strange particle signatures of the new QGP phase, see Chaps. 31 and 32, while Hagedorn focused his own work soon on models of this transition, see Chap. 24. Even though we published a lot of our work in separate publications, we exchanged our manuscripts and heeded mutual advice.

Strangeness and the Discovery of Quark-Gluon Plasma

Upon arrival at CERN on September 1, 1977 Tania assigned me to a three-person office, and one of my office mates was CERN-Fellow from the UK, Brian Combridge. Brian enters the annals of physics by being the first to correctly evaluate the production of charm quarks in *pp* collisions. This process turned out to be dominated by the two-gluon fusion reactions.

My time with Brian as an office mate was pivotal in two ways: I learned much about the working of perturbative QCD, and about the importance of glue in the production of heavy quark flavor. When Rudolph Bock asked me to present how QGP can be discovered at the GSI workshop in October 1980, I placed emphasis on strangeness flavor as a possible signature. Looking back, I believe I turned to strangeness because Brian Combridge primed me with the story of charm production. This was a natural step given that the temperature of QGP formation Hagedorn and I computed was close to strange quark mass estimates.

The first strangeness signature of QGP arguments seen at the end of Chap. 27 rely on the assumption of a strangeness abundance equilibrium. One of participants at the GSI workshop, József Zimányi, went home to work out if this hypothesis could be true. Within a few months I learned that the outcome of this investigation, involving Tamás Biró (see Chap. 5), challenged my strangeness chemical equilibration hypothesis in QGP.

Unfortunately, I missed the Summer 1981 seminar József Zimányi gave in Frankfurt; I saw his work only after it was written up and circulated as a preprint in November 1981. I was interested in technical details of Biró and Zimányi work since rumors were spreading that Zimányi had shown in his lecture that the Rafelski-Hagedorn work was wrong. Indeed, the results of Hagedorn-Rafelski showing the dominance of particle production process in relativistic colliding nuclear matter were in plain contradiction to the thrust of the relativistic heavy ion collision work by some of my colleagues in Frankfurt. They assumed that the collision energy was flowing into hydrodynamic compression of nuclear matter. Later experiments established that Hagedorn-Rafelski results showing particle production were correct.

The Frankfurt nuclear matter compression hypothesis also derailed, as noted at the end of this paragraph, much of the work of Biró-Zimányi. However, the real issue with this work was elsewhere. From a first view of their preprint it was clear to me that the input from the all-important Brian Combridge's work on QCD flavor production was not present: the Feynman diagram figure showed that the kinetic model for production of strangeness flavor included only light quark annihilation on antiquarks. Thermal antiquarks are themselves quite rare in the baryon dense QGP under consideration in Frankfurt, and this antiquark based process was thus very, very slow. What was missing was the two-gluon fusion process.

The QCD-glue strangeness chemical equilibration paper was prepared in collaboration with Berndt Müller before the end of 1981 and published soon after. These critical results are described in Chap. 31 and also in Chap. 32. For the following several years I worked out many details of strangeness and strange antibaryon signature working with Berndt, and with a student, Peter Koch. These results stimulated the experimental work described in Chap. 15 by Emanuele Quercigh, with some results shown in Chap. 33. The large 20-fold enhancement found was, in my eyes, the cornerstone of the CERN February 2000 QGP discovery story.

Among my favorite of Hagedorn's letters is the one dated 19 September 1995. It was written upon reception from publishers of a copy of the proceedings volume of a meeting.[3] I had placed Hagedorn's name on the distribution list, hoping he would enjoy the contents, but not expecting that he would read it front to back, which he did.

Hagedorn writes: "I just received here *Strangeness in Hadronic Matter* thank you sincerely. So much has happened since you told me for the first time about your ideas and considerations of strangeness in QGP.[4] Your idea has proved itself to be fruitful, exciting and—hopefully!—at the end decisive. Shall I live to see the unambiguous evidence and prove of the existence of quark-gluon plasma? Maybe this does not matter, I am anyway fully convinced, where else can the phase transformation (which surely is present) otherwise lead?"

This event was followed by continued discussion between us about the rapidly emerging results from CERN strangeness experiments. Hagedorn especially appreciated—in the historical perspective of his own work—the universality of strange particle and antiparticle transverse energy spectra showing that both particles and antiparticles had a common thermal source. In the following few years we agreed that the observed patterns of strange antibaryon enhancement, and the universal nature of evaporation spectra of particles confirm QGP discovery, a point more thoroughly described by Emanuele Quercigh in Chap. 15.

Retirement

Another impression that I wish to place under the spotlight, as it also has affected many others at CERN since, concerns Rolf Hagedorn planning his retirement. I worked closely with him while he was 58–64 years old, and at CERN the retirement age was then, and still is today, 65. One day Hagedorn told me that he took a course on 'How to Retire'. He became convinced that he must follow one piece of his classroom advice: he ought to reduce his work load gradually even before reaching the age of 65, so that when he reached 70 he would approach near zero level of scientific activity; the time lost to CERN before his retirement age could be more than made up by his work after retirement.

[3] J. Rafelski, *Strangeness in Hadronic Matter* AIP Conference Proceedings **340**, American Institute of Physics (New York 1995).

[4] Hagedorn proposes the date "1983(?)" but it must have been sometime 1979/1980.

Hagedorn believed that the worst scenario for him would be to work full steam till the age of 65, and then to completely drop the pen. He thought this was unhealthy and for most scientists anyway impossible, as it is difficult for aged men to work full steam but also for a scientist to stop thinking. Hagedorn would never proceed without proper agreement with CERN; in other words, he saw the need to create an emeritus status which allows continuation in the research program for retired personnel. Maurice Jacob says in Chap. 3 a few things about the ensuing negotiations that have led to the recognition of the Emeritus Scientist status at CERN. According to Maurice, Hagedorn was the first to receive this recognition upon his retirement.

Rolf Hagedorn retired on 31 July, 1984, after more than 30 years of service to CERN. On 30 July, 1984, the Director General (Herwig Schopper) addressed Hagedorn in his letter: "Following a proposal made by your Division Leader (Maurice Jacob), I am happy to grant you the possibility of continuing your research activities at CERN on an unremunerated basis. ... I should like to take this opportunity to congratulate you on your recent completion of 30 years of service and thank you for the contribution you have made to the success of this Laboratory. Wishing you good health and a happy retirement I remain, *Mit allen guten Wünschen* Yours sincerely, *Herwig Schopper*."

I should add that while the initial plan Hagedorn had was to phase out by the age of 70, he changed the formula: on one hand our collaboration progressed and the topic of heavy ion collisions turned hot in 1979 just as he planned to begin to work less, while at the same time, CERN was still working towards developing the emeritus status. In essence the onset of the plan was postponed to the date of his formal retirement in 1984. Thus in 1994 Hagedorn still remained hard at work—"The long way to the Statistical Bootstrap Model" is his 1994 account of the development of SBM, see Chap. 17.

From personal correspondence I know that Hagedorn followed scientific developments with great interest until a few months before his death. To be specific his last long typed letter (with many attachments) which we worked through at CERN in person, dated 25 August, 2002, he apologizes about typing as handwriting was becoming difficult. He comments on several recent contributions I made with his usual precision "... a few typos are marked in red" in the attached preprint he read and annotated. In another comment on a recently published book[5] he says "I read the section on H(adronic)-Gas, I could not write it better". I believe he meant every word.

Hagedorn turns then to the main topic of his letter and our meeting: I passed on to him the entire draft volume (800 pages!) of the material selected, and commentaries written for the annotated reprint volume *Quark-Gluon Plasma: Theoretical Foundations* which I was working on with Joseph Kapusta and Berndt Müller. Hagedorn made many comments which were incorporated in the final

[5] J. Letessier & J. Rafelski, *Hadron and Quark-Gluon Plasma*, (Cambridge, UK, 2002).

version of the volume. However, our volume was not finished until after Hagedorn's death, and thus we dedicated this work to him.[6]

As just noted, the health of Hagedorn was failing. At the end of the August 2002 2-day meeting he came out to say that he did not expect to meet me again; he already had been told about an aggressive cancer. Indeed I could not visit him before he passed, a little more than 6 months after this meeting.

1.2 The Righteous Man

There was a clear sense of absolute morality around Hagedorn. He would not leave a stone unturned to correct an error or an injustice. When reviewing the work of others he did not hide in anonymity; instead he sought permission of the editors to contact the authors to explain to them in person any required corrections, or to sign the positive reviews. But there were other expressions of his strong convictions:

Helping Those in Need

Rolf Hagedorn was always ready to help those in need. When a colleague and collaborator arrived from beyond the iron curtain, and told him that he had decided not to return home, becoming a refugee, Hagedorn spent weeks looking for a place that would take him. When the state of war in Poland made life there difficult in the early 1980s, and one of our friends and collaborators was imprisoned, Rolf worked incessantly to ease the burden on his friend in Poland. Hagedorn, a former prisoner of war, knew well what internment meant to a scientist.

Similarly, the fate of the prominent Soviet dissidents Andrei Sakharov and Youri Orlov preoccupied him much of the time, and he left nothing undone to further their cause. Certainly the Soviet empire was not brought down by Rolf Hagedorn, but he was definitely an important force that helped our colleagues in the East fight for their freedom: knowing that people like Rolf were there to stand behind them in bad times was a great support for their cause.

When the cards turned and the iron curtain fell, a different type of injustice attracted Hagedorn's attention. Now Hagedorn stood up for the rights of those that the revolution in the East suddenly left in limbo: before curtain's fall some scientists were among the 'privileged'; overnight they became jobless, and were scorned as collaborators of the communist regime. Hagedorn knew better, and had the moral privilege by having stood in for the freedom and the truth at earlier time. His cause

[6] J. Kapusta, B. Müller & J.Rafelski, *Quark-Gluon Plasma: Theoretical Foundations; An annotated reprint collection*, Elsevier, (Amsterdam 2003).

was again the right one, and he prevailed in his battles, for example for the rights of his close collaborator Johannes Ranft.

Le Chambon: A Short Story Outside the Physics Context

Nobody asked who was Jewish and who was not. Nobody asked where you were from. Nobody asked who your father was or if you could pay. They just accepted each of us, taking us in with warmth, sheltering children, often without their parents-children who cried in the night from nightmares; by Elizabeth Koenig-Kaufman, a former child refugee in Le Chambon.[7]

As years passed I have become more aware of the relation that Hagedorn must have had with Le Chambon. What I learned about begins in Fall 1963, when, as Maurice Jacob describes it in Chap. 3 they met in India; at that time, Hagedorn had enrolled his young daughter at the Boarding School Le Collége-Lycé Cv́enol International in Le Chambon. A school at the time filled with children associated with the holocaust survivors, a school located in a small village 4.5 h long hours by car from CERN, just about 'nowhere' in the midst of France. If you were not aware what happened in Le Chambon, this school is hard to find and for this reason the school is about to close today. However, this is a place Hagedorn and his wife liked to ride horses in the hills of the French Central Plateau, a place he turned to within a relatively short time after his arrival at CERN, at a time at which the story of this remarkable place was not yet told. Is this just a coincidence?

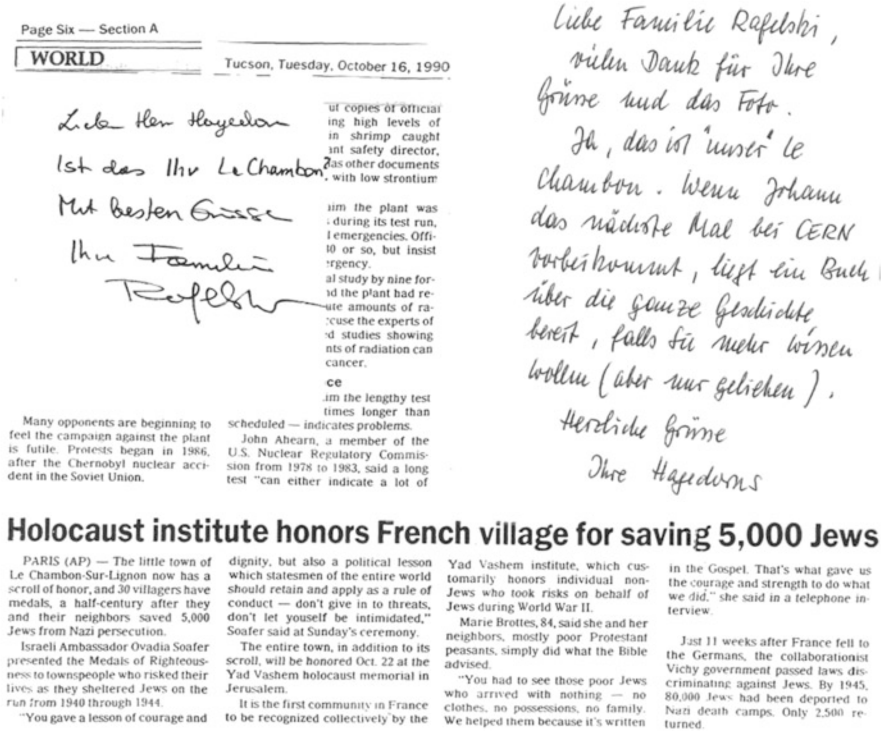
Let me tell the rest of the story. Aside of music which Hagedorn loved as is also described by Maurice Jacob in Chap. 3, Hagedorn liked "…a little History of Arts and related topics" which is a quote from his 1954 personal short biography as printed below. This in turn led to his interest in photography, a topic also raised by Maurice. Once he had time, in retirement, Hagedorn learned to create his own color prints. He mentioned this to me, later I realized, as a warning. In September 1989—about 10–11 years after taking me, along with his wife and mine, on a long weekend trip to Le Chambon-Sur-Lignon—he had sent a set of A4 large prints from this event, which he was keen to tell me, he made himself. As Maurice Jacob ably describes Hagedorn liked photography, so there are many more pictures he could print besides the Le Chambon event, but he did not.

I kept these prints on my desk while developing a plan to thank Hagedorn appropriately. In the interim the photographs reminded me of our visit to Le Chambon-Sur-Lignon a decade earlier, and the name of this village, long forgotten, was in consequence in my mind. I did recall that these photographs were taken at local spots important to Hagedorn who took us to these places and who set up the photo shots in detail.

[7] Opening of the entry "Le Chambon-sur-Lignon" at web-based "Holocaust Encyclopedia".

Reading my Tucson daily paper on October 16, 1990, nearly a year after receiving the photo prints, I noticed that this rural French Village Le Chambon-Sur-Lignon, where we had spent a memorable weekend with the Hagedorns, was subject of a long report: "…entire town will be honored on October 22, 1990 at the Yad Vashem holocaust memorial in Jerusalem." What, an entire village? That was a circumstance out of the ordinary. I shipped this article shown in Fig. 1.7 to Hagedorn. Since I was sending the original to Hagedorn, I copied the article, fortunately along with a short pertinent note to keep the details in memory.

My note said (in German) *Dear Hagedorn, Is this your Le Chambon-Sur-Lignon? With best regards, your family Rafelski*. On the right in Fig. 1.7, in return mail *Dear Family Rafelski, many thanks for your greetings and the photo. Yes, this is "our" Le Chambon-Sur-Lignon. Should you want to know more, a book addressing the entire story will be waiting for Johann at the time of his next visit to CERN (but only on loan). Yours very sincerely Hagedorns*. I was not to come to CERN for some time and when I returned I did not raise the matter of Le Chambon, and Hagedorn did not either, as I am sure today, he waited for me to step forward. The book he mentions



Page Six — Section A

WORLD

Tucson, Tuesday, October 16, 1990

Liebe Herr Hagedorn
Ist das Ihr Le Chambon?
Mit besten Grüsse
Ihre Familie
Rafelski

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scheduled — indicates problems.

John Ahearn, a member of the U.S. Nuclear Regulatory Commission from 1978 to 1983, said a long test "can either indicate a lot of

Liebe Familie Rafelski,
vielen Dank für Ihre
Grüße und das Foto.
Ja, das ist 'unser' Le
Chambon. Wenn Johann
das nächste Mal bei CERN
vorbeikommt, liegt ein Buch
über die ganze Geschichte
bereit, falls Sie mehr wissen
wollen (aber nur geliehen).
Herzliche Grüße
Ihre Hagedorns

Holocaust institute honors French village for saving 5,000 Jews

PARIS (AP) — The little town of Le Chambon-Sur-Lignon now has a scroll of honor, and 30 villagers have medals, a half-century after they and their neighbors saved 5,000 Jews from Nazi persecution.

Israeli Ambassador Ovadia Soafer presented the Medals of Righteousness to townspeople who risked their lives as they sheltered Jews on the run from 1940 through 1944.

"You gave a lesson of courage and dignity, but also a political lesson which statesmen of the entire world should retain and apply as a rule of conduct — don't give in to threats, don't let youself be intimidated," Soafer said at Sunday's ceremony.

The entire town, in addition to its scroll, will be honored Oct. 22 at the Yad Vashem holocaust memorial in Jerusalem.

It is the first community in France to be recognized collectively by the Yad Vashem institute, which customarily honors individual non-Jews who took risks on behalf of Jews during World War II.

Marie Brottes, 84, said she and her neighbors, mostly poor Protestant peasants, simply did what the Bible advised.

"You had to see those poor Jews who arrived with nothing — no clothes, no possessions, no family. We helped them because it's written in the Gospel. That's what gave us the courage and strength to do what we did," she said in a telephone interview.

Just 11 weeks after France fell to the Germans, the collaborationist Vichy government passed laws discriminating against Jews. By 1945, 80,000 Jews had been deported to Nazi death camps. Only 2,500 returned.

Fig. 1.7 Included with my annual Holiday Greetings 1990/1991 was a photo I prepared for Hagedorn, Fig. 6.4 on page 48, and the article from our daily paper I noted by accident in Tucson local paper, The Arizona Daily Star of October 16, 1990 must have been: *Lest Innocent Blood Be Shed (Story of the Village of Le Chambon)* by Philip Hallie—first printed in 1978.

As I write this down, I further recollect how we were having breakfast one morning in Le Chambon, I realize today that these middle-aged people of Le Chambon who in a collective act of valor saved maybe 3,000–5,000 Jewish refugees from certain death, were serving us coffee. At the time I noted that the Hagedorns had a strong personal connection in the hotel we were staying. When we visited Le Chambon-Sur-Lignon, Hagedorn was among people with the same mentality as his own. People who did the right thing, even in face of punishment by death. I believe today that the people of Le Chambon-Sur-Lignon, and Hagedorns, were more deeply connected.

It is known that the activities of the population of Le Chambon benefited from a mole among Nazis sending out timely warnings, and preventing adverse encounters which would have tragic consequences for the refugees, and the entire population of Le Chambon. I can only speculate that Hagedorn knew about Le Chambon before he arrived at CERN; perhaps someone told him during his years in Africa, or while he was in the war prison camp in US. But judging by the way the Hagedorns took us around the hills of Le Chambon, in depth of my heart I think that a more direct involvement of Hagedorns in the war story of Le Chambon is possible.

1.3 Rolf Hagedorn: Biographical Information

Rolf Hagedorn Curriculum Vitae[8] *1954*

I was born in 1919 at Wuppertal-Barmen. My parents, Max and Linda Hagedorn (born Reinecke), are both alive today. At the age of six I entered the elementary school and 4 years later the "Städtisches Realgymnasium Wuppertal-Barmen" where I passed the final examination (Abiturium) Easter 1937. Thereafter I joined the Reichsarbeitsdienst[9] and in November 1937 the Armed Forces since I intended to complete my military service before beginning the university course in order not to interrupt it. But at the end of 1939, when I was to be released, the war began and I had to stay with the Luftwaffe. During the war, I spent a long time in North Africa where I was captured May 1943 and was brought to the USA. There in the prisoner-of-war Camp Crossville (Tennessee) I began studying Mathematics, Physics and also a little History of Arts and related topics. Further I had to teach a high school class in Physics on a basic level. After having returned in January 1946, I continued my studies in Göttingen, where I decided to become a theoretician. Consequently I was a pupil of Prof. R. Becker. In 1950 I passed the diploma-examination with a

[8] CERN job application form dated January 1954.

[9] Translated: Reich Labor Service. From June 1935 onwards, men aged between 18 and 24 had to serve 6 months before entering their military draft service.

work on the theory of Lamb-shift in nonrelativistic Quantum electrodynamics (not published). This was followed by a paper in the theory of Barium-titanate as a thesis in spring 1952. Since June 1952 I have been working at the Max-Planck-Institute für Physik, Göttingen, on nuclear physics, especially on the evaporation stars in nuclear emulsions.

CERN Appointment

Hagedorn began his CERN appointment on 1 April, 1954 in the "Proton Synchrotron (PS) Division". He was offered a permanent appointment on 28 September 1960 effective 1 January, 1961 working in the "Theoretical Studies (TH) Division". His job description: "The main activity of Dr. Hagedorn should concern theoretical investigations and computations of direct importance to the planning and interpretation of experiments in the CERN high energy physics program, in particular the investigations based on the use of statistical models for particle production; or other similar studies as may become of interest in the evolution of this subject. In addition he should devote a reasonable fraction of his time to the study of other parts of theoretical physics so as to be prepared to adjust the orientation of his work to the unpredictable needs of the future development of high energy physics".

CERN Obituary[10]: Rolf Hagedorn 1919–2003

This official CERN document was drafted by Torleif Ericson and Johann Rafelski and published by CERN Courier, and in abbreviated format in the official CERN bulletin, this shorter version follows (with added precise birth and death data):

Rolf Hagedorn, the theorist who introduced the concept that hadronic matter has a melting point, died on 9 March, 2003 in Geneva. He was born 20 July, 1919 in Wuppertal, Germany.

After studies in Göttingen he came to CERN in Geneva in 1954 as an accelerator theorist. He joined the CERN Theory Group after its transfer in 1957 from Copenhagen to Geneva (Fig. 1.8) and he was a senior physicist in the Division when he retired in 1984.

He continued his research after retirement, and up to very recently he made pertinent contributions in developments in the field of relativistic heavy ion collisions.

As an accelerator physicist he developed the theoretical predictions for the particle spectra initially observed when the CERN PS first began operation, which

[10]Copyright CERN 2014—CERN Publications, DG-CO; Bulletin Issue 14/2003, http://cds.cern.ch/record/46337.

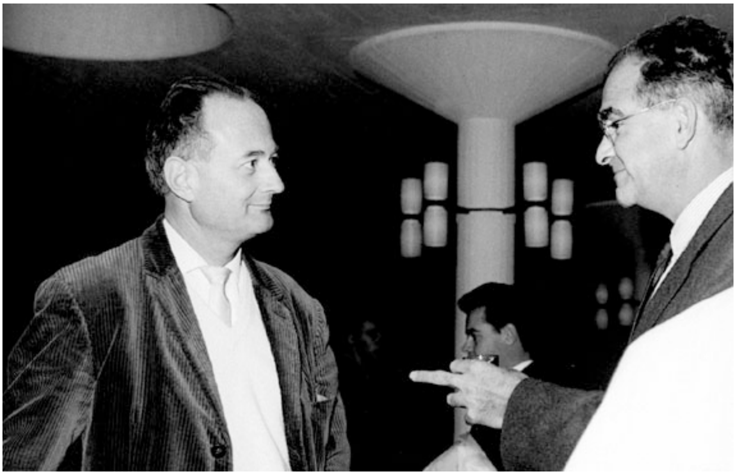

Fig. 1.8 Rolf Hagedorn 1964, (on *left*), in conversation with Victor Weisskopf, Director General of CERN; *Credit: CERN photo 64-11-103*

was important for the optimization of secondary beams. He then developed the statistical theory of meson production in considerable detail up to very high energies. It was a consequence of these studies that he found that one should expect a limiting temperature in hadronic collisions, the Hagedorn temperature. This picture has had a major impact on theoretical thinking and on our understanding of the properties of hot hadronic matter, which is important now in the heavy ion program. Since the picture is applicable to any exponentially rising particle mass spectrum it is also influencing the development of string theories.

Among contributions to CERN, Hagedorn developed one of the earliest user-friendly interactive computing programs for algebraic manipulations, the SIGMA.

Rolf Hagedorn was a person of the highest scientific integrity and standards of reasoning. He was always willing to help colleagues and his comments were usually penetrating and deep.

He will be much missed by friends and colleagues.