Why are we here:

Hagedorn Temperature is the pivotal idea that opened to study high energy density matter defining our Universe in primordial times. It was put forwards at CERN 50 years ago. We celebrate the anniversary today.

Rolf Hagedorn has opened at CERN the path to the study of hot hadronic matter which we call today quark-gluon plasma. It seems appropriate to remember the physics progress made in the past 50 years and how our view of the Universe evolved in this half century.

Lasting Influence Illustrated by a few stepping stone developments.

Dr. Rolf Hagedorn
Scientific and Technical
Services.

CERN/6824

Personal and Confidential

28 September, 1960

Dear Dr. Hagedorn,

It gives me great pleasure to inform you that it is my intention to offer you an indefinite appointment with this Organization to take effect from 1 January, 1961. This date has been decided in accordance with the present policy of CERN not to offer such appointments to selected staff members normally before their completion of at least six years' service in the Organization.

This indefinite appointment is for a post in the Theory Division of CERN.

It is intended that you devote your time partly to investigations and computing problems associated with the experimental programmes of CERN, such as the use of statistical models for predicting particle production, and partly to those aspects of theoretical physics that will enable you to keep abreast of modern developments in

How it all begun: Heisenberg hired Hagedorn trained by preeminent thermodynamics theorist Becker to work on his cosmic emulsion-star hobby, what we know to be the very precursor to hot hadronic matter, and sends him of to CERN to continue; and CERN D.G. Adams charges Hagedorn with this task.

1964/65 Revolution: These ideas determine our times

- Hagedorn: T_{H} & SBM hadronic matter
- matter made of Quarks
- Higgs & Standard Model of Particle Physics
- The big-bang (Penzias-Wilson CMB)

Our time line:

1. 50 years ago – Melting hadrons: birth of hadronic matter
2. 35 years ago – Boiling quarks: at T_{H} hadrons $\Leftrightarrow$ quarks
3. 15 years ago – Quark-gluon plasma discovery
4. Today – Searching with QGP for new physics

T_H has a tormented birth

WITHDRAWN

Hagedorn 1960-1964: Fermi model produces too few pions - could this mean particles are distinguishable ?

9716/TH.483
12 October 1964

PRELIMINARY VERSION

THERMODYNAMICS OF D I S T I N G U I S H A B L E PARTICLES - A KEY TO HIGH ENERGY STRONG INTERACTIONS ?

R. Hagedorn
CERN - Geneva

A B S T R A C T

A new kind of thermodynamical model for strong interactions at high energies is proposed. We start from the fact that strong interactions produce so many possible particle states (from π over its resonances to nucleons, strange particles and their resonances, up to highly excited "fireballs") that in an actual process each of these states practically never occurs more than once. We use this in order to treat the very first instant of a high-energy collision by statistical thermodynamics of a system of an illimited number of d i s t i n g u i s h a b l e particles. The model shows surprising properties : there exists a universal highest possible temperature T_0 of the order of 150-200 MeV (corresponding to $\approx 10^{12}$ °K) which governs all high-energy processes of strongly interacting particles, independently of the actual energy and independently of the particle number, from cosmic ray jets down to elastic scattering.

ARCHIVES

Remarks to the "PRELIMINARY VERSION" of

THERMODYNAMICS OF D I S T I N G U I S H A B L E PARTICLES - A KEY TO HIGH ENERGY STRONG INTERACTIONS ?

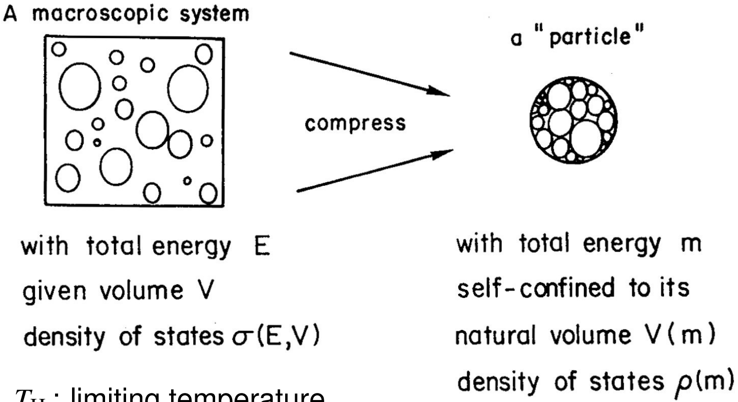
R. Hagedorn

I have written and distributed this paper too early. The logical difficulty mentioned on p. 41 has been removed as follows and the result is disappointing :

Now everything depends on the asymptotic behaviour of the mass spectrum $\rho(m)$

1) if $\rho(m)$ grows faster than exponentially, log Z diverges for all $T > 0$. No thermodynamics is possible.

A model is born: **SBM**=Statistical Bootstrap Model



T_{H} : limiting temperature

Idea yields exponential mass spectrum: $\rho \propto \dfrac{\mathbf{e^{m/T_H}}}{\mathbf{(m_0^2 + m^2)^{a/2}}}$

Jan. 1965: Nuovo Cim. Supp. **3** 147 (1965): SBM, T_{H}

65/166/5 - TH. 520
25 January 1965

STATISTICAL THERMODYNAMICS OF STRONG INTERACTIONS AT HIGH ENERGIES

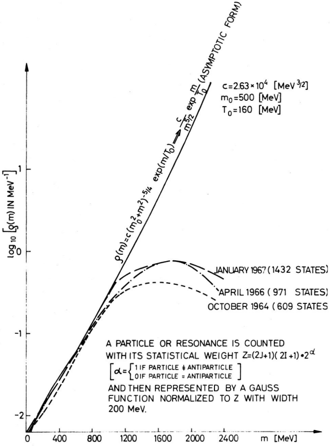
R. Hagedorn
CERN - Geneva

A B S T R A C T

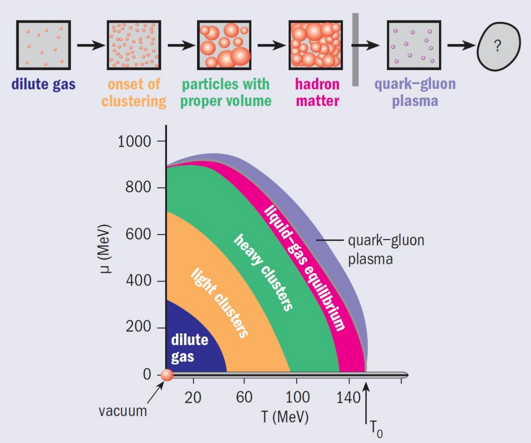
In this statistical-thermodynamical approach to strong interactions at high energies it is assumed that higher and higher resonances of strongly interacting particles occur and take part in the thermodynamics as if they were particles. For $m \to \infty$ these objects are themselves very similar to those which shall be described by this thermodynamics. Expressed in a slogan: "We describe by thermodynamics fire-balls which consist of fire-balls, which consist of fire-balls, which ...". This principle, which could be called "asymptotic bootstrap", leads to a self-consistency requirement for the asymptotic form of the mass spectrum. The equation following from this requirement has only a solution if the mass spectrum grows exponentially:

$$\rho(m) \xrightarrow[m \to \infty]{} \text{const.}\, m^{-5/2} \exp\left(\frac{m}{T_o}\right).$$

T_o is a remarkable quantity: the partition function corresponding to the above $\rho(m)$ diverges for $T \to T_o^-$. T_o is therefore the highest possible temperature for strong interactions. It should - via a Maxwell-Boltzmann law - govern the transversal momentum distribution in all high energy collisions of hadrons (including e.m. form factors, etc.). There is experimental evidence for that, and then T_o is about 158 MeV ($\approx 10^{12}$ °K). With this value of T_o the asymptotic mass spectrum of our theory has a good chance to be the correct extrapolation of the experimentally known spectrum.

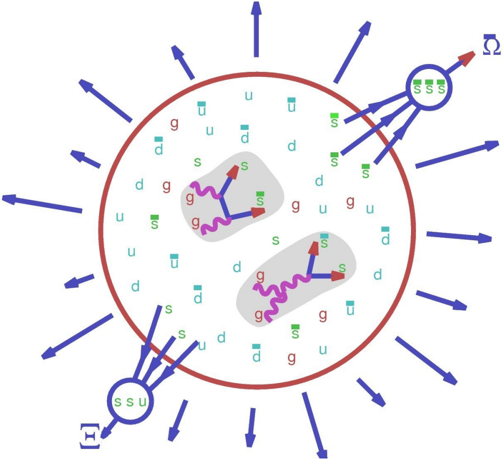


Phases of Hadronic Matter 1980



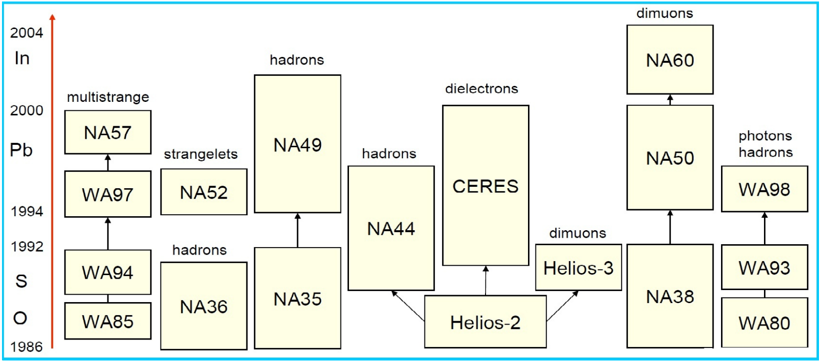
From J. Rafelski and T. Ericson: CERN Courier memorial article "Tale of Hagedorn Temperature" – adapted from Hagedorn and Rafelski 1980 manuscript, found in similar format in Letessier-Rafelski book "Hadrons from QGP".

Strangeness Signature of QGP 1980-86

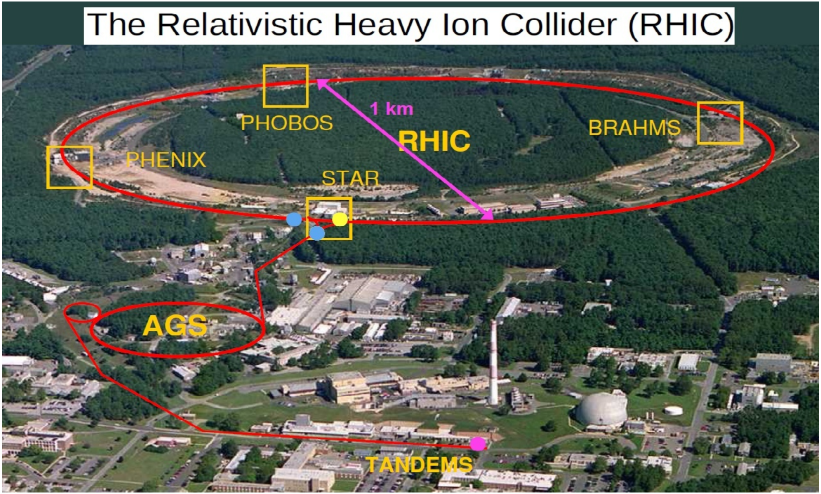


A signature of QGP was ‘requested’ for the QM1 meeting at GSI – and further developed in collaboration with Berndt Müller.

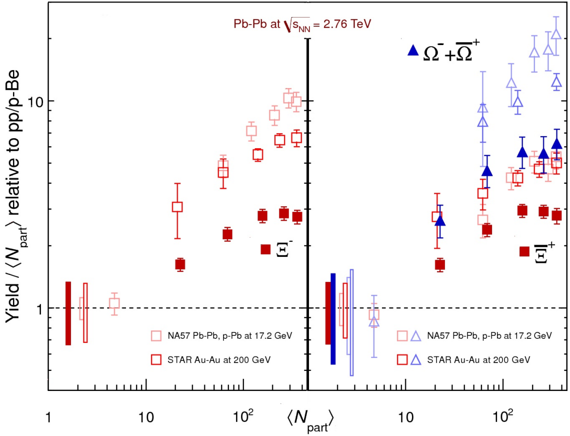
CERN RHI experimental SPS program is born 1980-86



A new ‘large’collider is build at BNL: 1984-2001



My favorite: Strange Antibaryons: SPS, RHIC, ALICE: 1996-2014

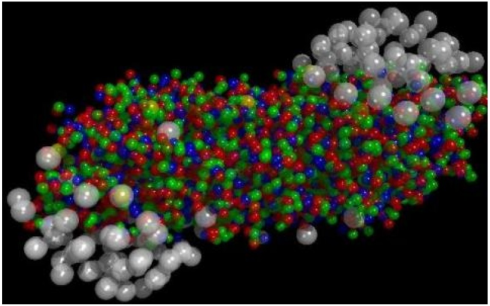


Largest 'Medium Effect'and a characteristic signature of QGP

CERN press office

New State of Matter created at CERN

10 Feb 2000

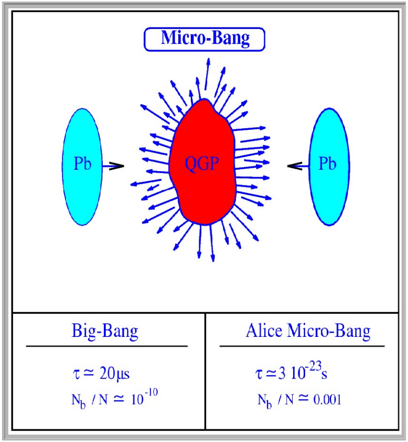


At a special seminar on 10 February, spokespersons from the experiments on CERN* 's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

press.web.cern.ch/press-releases/2000/02/new-state-matter-created-cern

9AM, 18 April 2005; US – RHIC announces QGP Press conference APS Spring Meeting

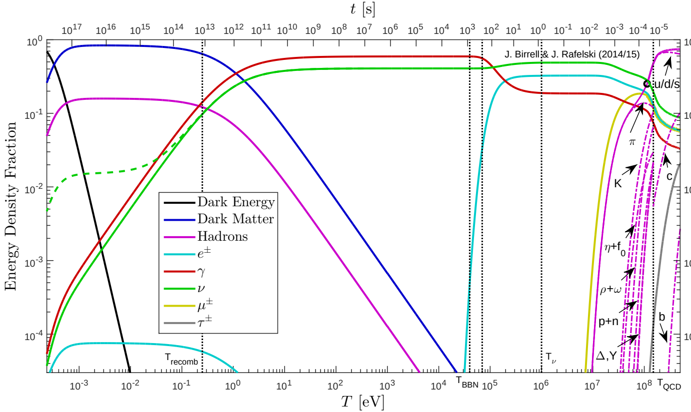
Connection to Relativistic Heavy Ion Collisions



- Universe time scale 18 orders of magnitude longer, hence equilibrium of leptons & photons
- Baryon asymmetry six orders of magnitude larger in Laboratory, hence chemistry different
- Universe: dilution by scale expansion, Laboratory explosive expansion of a fireball

$\Longrightarrow$ Theory connects RHI collision experiments to Universe

The Universe Composition Changes



dark energy matter radiation ν, γ leptons hadrons

$\Longrightarrow$ Different dominance eras

Valedictorian Lecture 1994