Charting the future frontier(s) of particle production

July 25, 2016

50 years since two new fundamental ideas

- Quarks+BE-Higgs → Standard Model of Particle Physics
- Hagedorn Temperature → New State of Elementary Matter

Topics today:

1. Quark-Gluon Plasma and Strangeness
2. Hadronization
3. Collision Transparency
4. Why are we into strong interactions
5. Optional: Krakow-Arizona collaboration time line

CERN 1983 – Strangeness – Hadron Collisions

STRANGENESS PRODUCTION IN THE QUARK GLUON PLASMA*

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and

CERN -- GENEVA

ABSTRACT

It is shown that perturbative QCD predicts abundant strange quark production in the plasma created in high energy nuclear collisions. Considering further the strange particle production in the hadronic gas phase, I show that the strangeness abundance in the plasma is 10-50 times higher as compared with the gas phase in similar thermodynamic conditions. Possible experiments leading to the identification of the plasma phase are described.

*Invited lecture at the 'Quark Matter 83', Brookhaven National Laboratory, September 26-September 30, 1983.

Ref. TH. 3745 - CERN October, 1983

HADRON NUCLEUS INELASTIC COLLISIONS AND FORMATION ZONE OF FAST HADRONS

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ABSTRACT

A method of determining the formation zone by measurement of absorption of the medium-energy hadrons created in nuclear matter is outlined. It is applied to recent data on the process $\pi^- A \to \bar{p} + X$ and used to estimate the formation zone of $\bar{p}$ at ~16 GeV/c.

Ref.TH.3765-CERN November 1983

STRANGE PARTICLE PRODUCTION IN pp AND pn REACTIONS

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ABSTRACT

A statistical model of particle production valid for a wide range of Feynman's x is developed and applied to describe strange particle production in hadronic collisions. Predictions of relative abundances of multiply strange hadrons are made which compare well with the available fragmentary data.

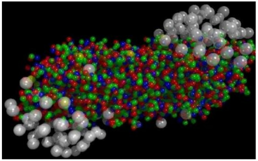
Ref.TH.3781-CERN December 1983

+33 Years: When and how did we discover QGP?

CERN press office

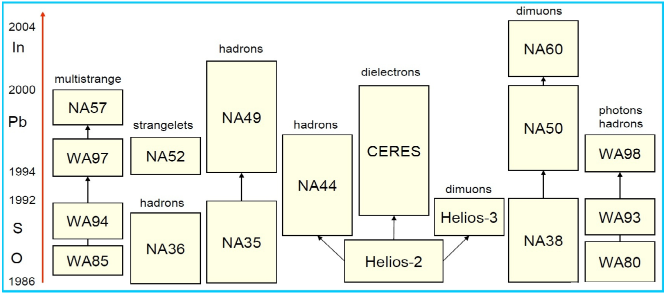
New State of Matter created at CERN

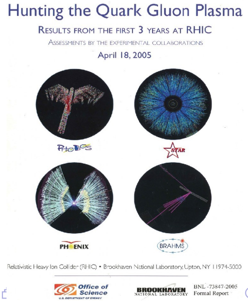
10 Feb 2000



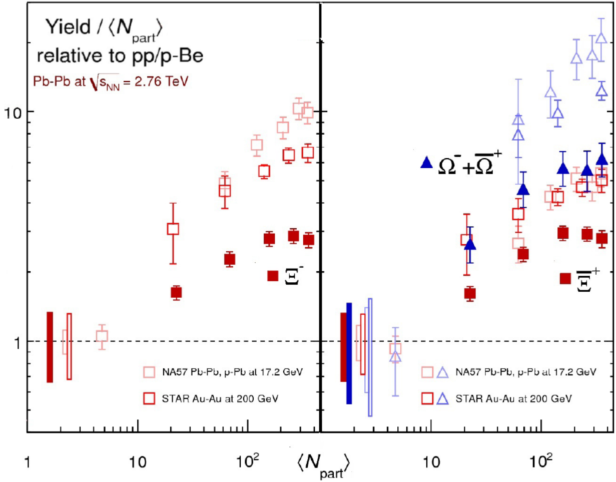
At the April 2005 meeting of the American Physical Society, held in Tampa, Florida a press conference took place on Monday, April 18, 9:00 local time. The public announcement of this event was made April 4, 2005:

EVIDENCE FOR A NEW TYPE OF NUCLEAR MATTER At the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL), two beams of gold atoms are smashed together, the goal being to recreate the conditions thought to have prevailed in the universe only a few microseconds after the big bang, so that novel forms of nuclear matter can be studied. At this press conference, RHIC scientists will sum up all they have learned from several years of observing the worlds most energetic collisions of atomic nuclei. The four experimental groups operating at RHIC will present a consolidated, surprising, exciting new interpretation of their data. Speakers will include: Dennis Kovar, Associate Director, Office of Nuclear Physics, U.S. Department of Energy's Office of Science; Sam Aronson, Associate Laboratory Director for High Energy and Nuclear Physics, Brookhaven National Laboratory. Also on hand to discuss RHIC results and implications will be: Praveen Chaudhari, Director, Brookhaven National Laboratory; representatives of the four experimental collaborations at the Relativistic Heavy Ion Collider; and several theoretical physicists.

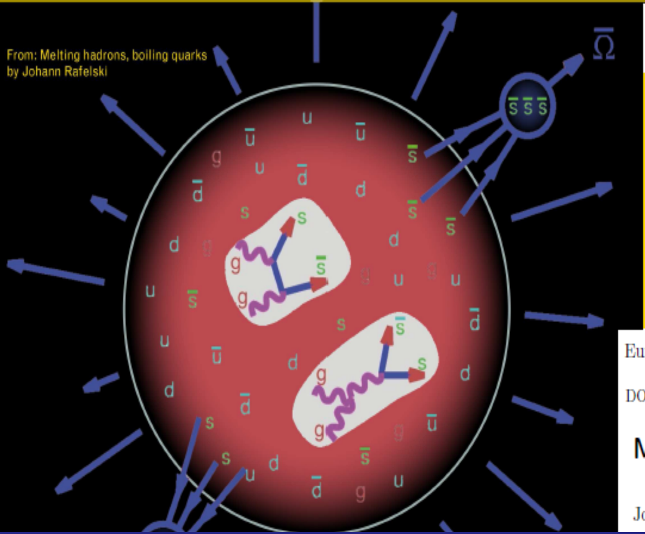




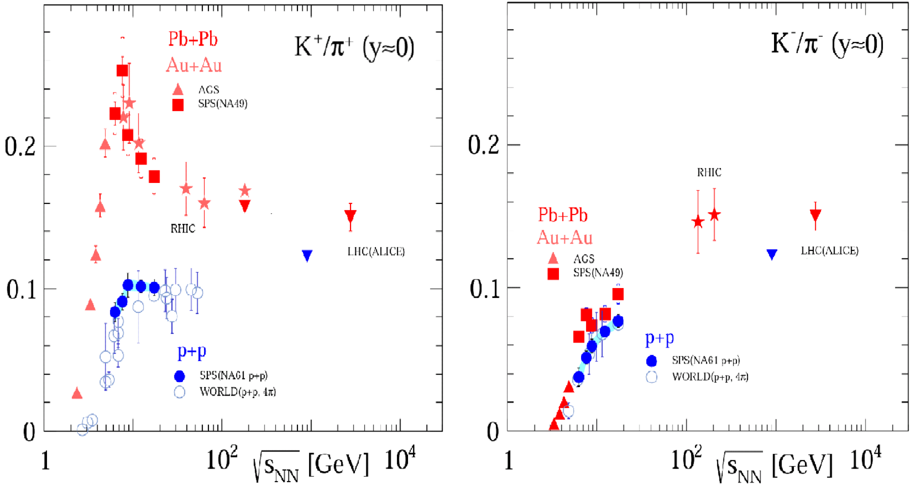
How: Strange Antibaryons – signature of QGP and largest QGP medium effect: SPS Emanuele Quercigh



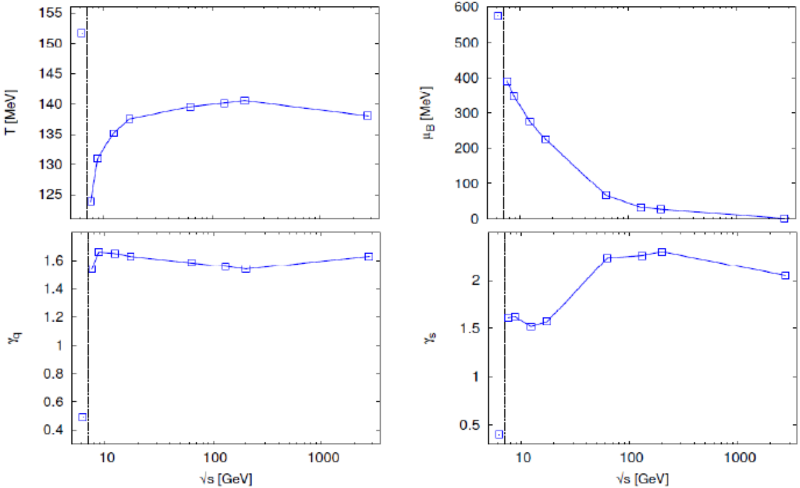
Why: multi step: make flavor, float in QGP, bind flavor



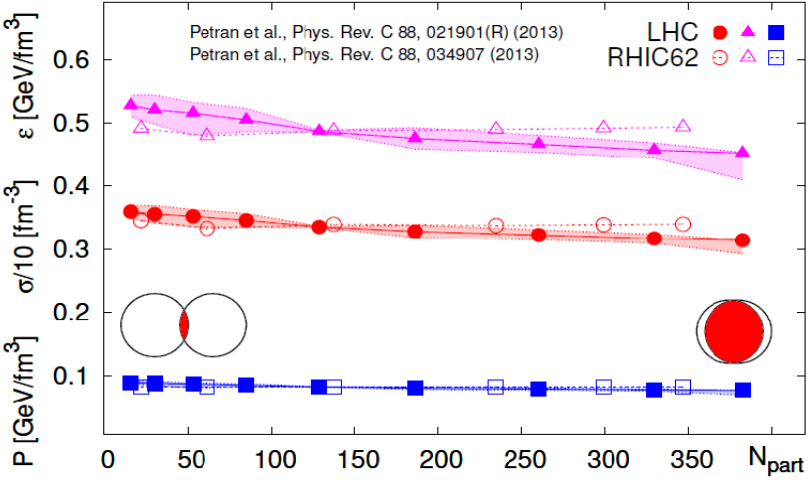
Strangeness excitation: Marek Gaździcki
All accessible energies SPS, RHIC, LHC = QGP



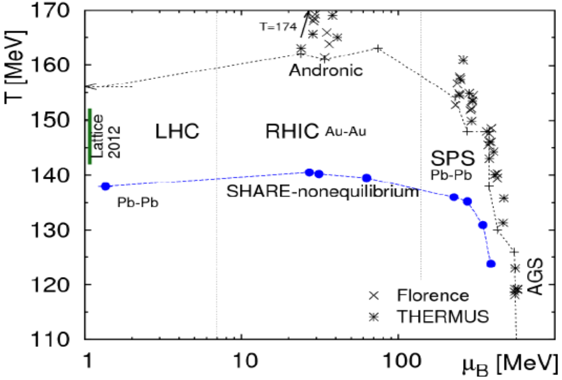
Hadronization: SPS–RHIC–LHC
SHARE parameters from particle yields



Universal Hadronization: RHIC vs LHC (also SPS)



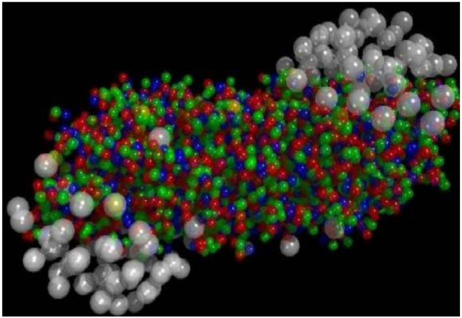
SHARE consistent with lattice QCD

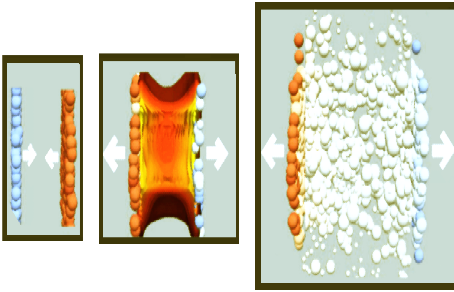


Chemical freeze-out MUST be below lattice results. For direct free-streaming hadron emission from QGP, T-SHM is the QGP source temperature, there cannot be full chemical equilibrium.

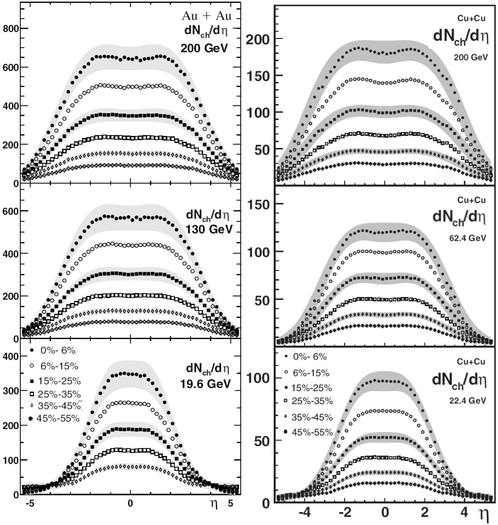
What exactly happens when pancakes collide?

This or this?

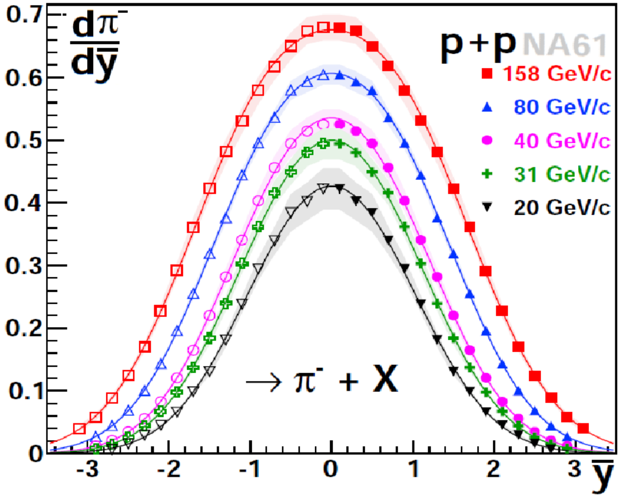




Without particle ID RHIC-Phobos



That is what we see with particle ID even for *pp*!



SPS, RHIC, LHC comparison

- SHARE based determination of hadronization condition reveals near perfect Universality of properties across the entire reaction energy domain and L-QCD consistency
- There are no discernible differences in strange antibaryon signature of QGP, at all energies where data exist there is clear evidence for the same new state of matter.
- At least up to $\sqrt{s_{\rm NN}} < 20\,$GeV (where particle ID'd data in 4π exists), and probably at much higher energies as well, there is no sign of the McLerran-Bjorken transparency – we see a pileup of energy at central rapidity. Baryon number deposition varies strongly as function of collision energy.

Four Pillars of QGP/RHI Collisions Research Program

RECREATE THE EARLY UNIVERSE IN LABORATORY:

Recreate and understand the high energy density conditions prevailing in the Universe when matter formed from elementary degrees of freedom (quarks, gluons) at about 30 μs after big bang.

QGP-Universe hadronization led to nearly matter-antimatter symmetric state, the later ensuing matter-antimatter annihilation leaves behind as our world the tiny 10^{-10} matter asymmetry.

STRUCTURED VACUUM-AETHER (Einsteins 1920+ Aether/Field/Universe)

The vacuum state determines prevailing fundamental laws of nature. Demonstrate by changing the vacuum from hadronic matter ground state to the deconfined quark matter ground state.

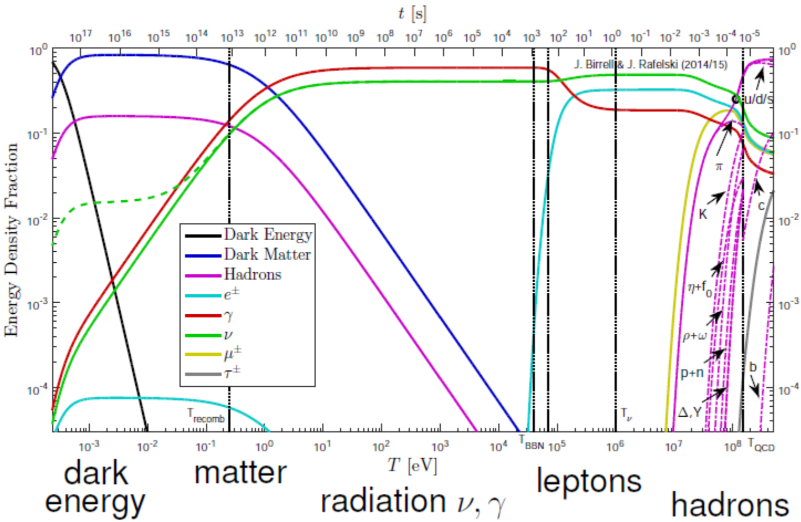
ORIGIN OF MASS OF MATTER –(DE)CONFINEMENT

The confining quark vacuum state is the origin of 99.9% of mass, the Higgs mechanism applies to the remaining 0.1%. We want to confirm the quantum zero-point energy of confined quarks as the mass of matter. When we 'melt' the vacuum structure setting quarks free the energy locked in mass of nucleons is transformed into thermal QGP energy.

ORIGIN OF FLAVOR

Normal matter made of first flavor family (u, d, e, ν_e). Strangeness rich quark-gluon plasma the sole laboratory environment filled with 2nd family matter (s, c, μ, ν_μ) – arguable the only experimental environment where we could unravel the secret of flavor.

The Universe Composition Changes



Origin of 10^{-9} baryon asymmetry

- Why seeking 10^{-9} baryon asymmetry at EW phase transition $T_{\rm EW} = 1000 T_{\rm had}$? Everybody knows things do not add-up; this demands of our community to look at the hadronizing Universe.
- Hadronization in early Universe at $T \simeq 150$ where oscillating neutrinos coupled to hadrons, heavy flavor c, b in abundance assuring sufficient matter over antimatter asymmetry, large nonequilibrium assured by need to annihilate 20% of total energy content put into antimatter. BUT we need baryon non-conserving processes!
- RHI to search for truly new physics: Are we sure that
  a) baryon number is conserved?
  b) energy balances out?
  'dark' radiation is compatible with Early Universe

ELSEVIER

Physics Letters B

Volume 741, 4 February 2015, Pages 77–81

Quark–gluon plasma as the possible source of cosmological dark radiation

Jeremiah Birrell, Johann Rafelski

Show more

doi:10.1016/j.physletb.2014.12.033

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Abstract

The effective number of neutrinos, N_{eff}, obtained from CMB fluctuations accounts for all effectively massless degrees of freedom present in the Universe, including but not limited to the three known neutrinos. Using a lattice-QCD derived QGP equation of state, we constrain the observed range of N_{eff} in

The Æther

Relativistically Invariant Aether 1920: Albert Einstein at first rejected æther as unobservable when formulating special relativity, but eventually changed his initial position, re-introducing what is referred to as the 'relativistically invariant' æther. In a letter to H.A. Lorentz of November 15, 1919, see page 2 in *Einstein and the Æther*, L. Kostro, Apeiron, Montreal (2000). Einstein writes:
It would have been more correct if I had limited myself, in my earlier publications, to emphasizing only the non-existence of an æther velocity, instead of arguing the total non-existence of the æther, for I can see that with the word æther we say nothing else than that space has to be viewed as a carrier of physical qualities.

In a lecture published in Berlin by Julius Springer, in May 1920, presentation at Reichs-Universität zu Leiden, addressing H. Lorentz delayed till 27 October 1920 by visa problems, also in Einstein collected works:

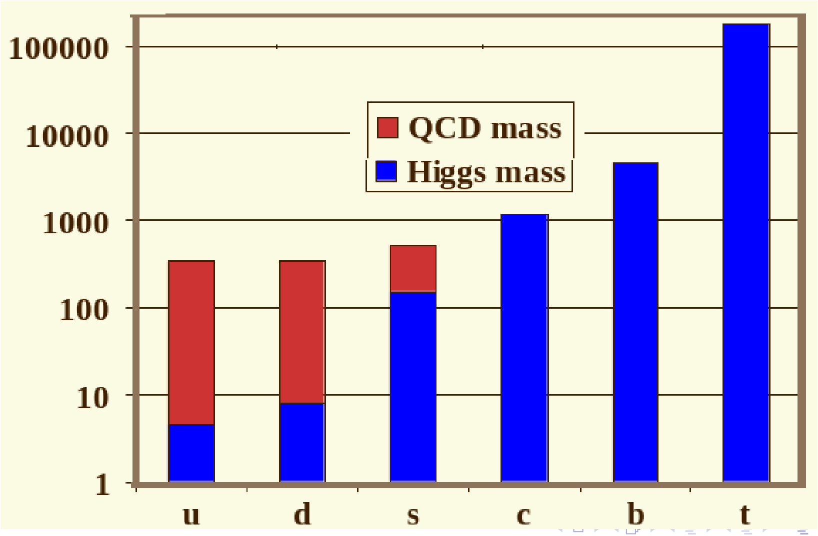
In conclusion:
...space is endowed with physical qualities; in this sense, therefore, there exists an æther. According to the general theory of relativity space without æther is unthinkable; for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time (measuring-rods and clocks), nor therefore any space-time intervals in the physical sense. But this æther may not be thought of as endowed with the quality characteristic of ponderable media, as (NOT) consisting of parts which may be tracked through time. The idea of motion may not be applied to it.

From Æther to QGP – Quantum Vacuum

Development of quantum physics leads to the recognition that vacuum fluctuations define laws of physics (Weinberg's effective theory picture). All this is nonperturbative property of the vacuum.

- The 'quantum æther' is polarizable: Coulomb law is modified; E.A.Uehling, 1935
- New interactions (anomalies) such as light-light scattering arise considering the electron, positron vacuum zero-point energy; Euler, Kockel, Heisenberg (1930-36);
- Casimir notices that the photon vacuum zero point energy also induces a new force, referred today as Casimir force 1949
- Non-fundamental vacuum symmetry breaking particles possible: Goldstone Bosons '60-s
- 'Fundamental electro-weak theory is effective - model of EW interactions, 'current' masses as VEV Weinberg-Salam '70-s
- Color confinement and high-T deconfinement Quark-Gluon Plasma '80-s

QCD CONFINEMENT = Quark Mass of Matter



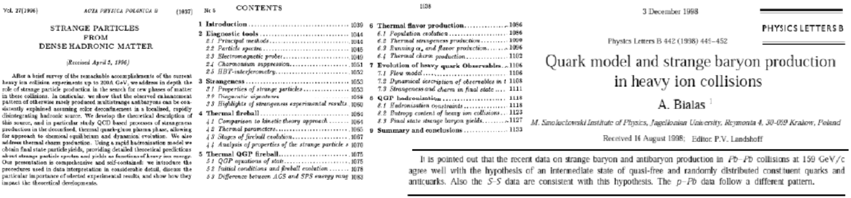
~~50~~ 80 more years along this path

- Unprecedented progress: accelerators barely started 80 years ago, particle production study begins in earnest 50 years ago; leading us to understand origin of mass of matter, the early Universe, the Æther =quantum vacuum.
- Much mystery remains: Why colliding hadrons make lots of entropy – what else is in quantum vacuum? What is baryon number and why matter is stable? Why three flavors?
- Kraków coffe houses, Zakopane mountains: These are essential tools assuring future progress and continued success for the large Krakow group that rose to World prominence in the past 50 years.

Kraków-Arizona I

1986-88 Efforts to visit each other succeed November 1988:
The State of Change in Poland will never leave my memory

1989-99 10 years of Zakopane School as a meeting point:
Strangeness review and AB strangeness in QGP



Vol. 27(1996) ACTA PHYSICA POLONICA B (1037) No 5

STRANGE PARTICLES
FROM
DENSE HADRONIC MATTER

(Received April 5, 1996)

After a brief survey of the remarkable accomplishments of the current heavy ion collision experiments up to 200A GeV, we address in depth the role of strange particle production in the search for new phases of matter in these collisions. In particular, we show that the observed enhancement pattern of otherwise rarely produced multistrange antibaryons can be consistently explained assuming color deconfinement in a localized, rapidly disintegrating hadronic source. We develop the theoretical description of this source, and in particular study QCD based processes of strangeness production in the deconfined, thermal quark-gluon plasma phase, allowing for approach to chemical equilibrium and dynamical evolution. We also address thermal charm production. Using a rapid hadronisation model we obtain final state particle yields, providing detailed theoretical predictions about strange particle spectra and yields as functions of heavy ion energy. Our presentation is comprehensive and self-contained: we introduce the procedures used in data interpretation in considerable detail, discuss the particular importance of selected experimental results, and show how they impact the theoretical developments.

CONTENTS

3 December 1998
PHYSICS LETTERS B
Physics Letters B 442 (1998) 445–452

Quark model and strange baryon production in heavy ion collisions

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Received 16 August 1998; Editor: P.V. Landshoff

It is pointed out that the recent data on strange baryon and antibaryon production in Pb–Pb collisions at 159 GeV/c agree well with the hypothesis of an intermediate state of quasi-free and randomly distributed constituent quarks and anticuarks. Also the S–S data are consistent with this hypothesis. The p–Pb data follow a different pattern.

Kraków-Arizona II

2000-06 Golden age of scientific collaboration

ELSEVIER Computer Physics Communications 167 (2005) 229–251

SHARE: Statistical hadronization with resonances

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Received 27 July 2004; received in revised form 9 November 2004; Available online 19 March 2005

Abstract

SHARE is a collection of programs designed for the statistical analysis of particle production in relativistic heavy-ion collisions. With the physical input of intensive statistical parameters, it generates the ratios of particle abundances. The program includes cascade decays of all confirmed resonances from the Particle Data Tables. The complete treatment of these resonances has been known to be a crucial factor behind the success of the statistical approach. An optional feature implemented is the Breit–Wigner distribution for strong resonances. An interface for fitting the parameters of the model to the experimental data is provided.

ELSEVIER Physics Letters B 633 (2006) 488–491

Balance of baryon number in the quark coalescence model

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Received 29 August 2005; received in revised form 7 November 2005; Available online 7 December 2005

The charge and baryon balance functions are studied in the coalescence hadronization mechanism of quark–gluon plasma. Assuming that in the plasma phase the $q\bar{q}$ pairs form uncorrelated clusters whose decay is also uncorrelated, one can understand the observed small width of the charge balance function in the Gaussian approximation. The coalescence model predicts even smaller width of the baryon–antibaryon balance function: $\sigma_{B\bar{B}}/\sigma_{+-} = \sqrt{2/3}$.

Kraków-Arizona III

2006-16 Mature friends

Johann Rafelski (right) wearing the traditional Krakow hat presented to him by Andrzej Bialas, the President of the Polish Academy of Arts and Sciences. (Image credit: Andrzej Kobos.)

CERN COURIER

Nov 23, 2011

Strangeness and heavy flavours in Krakow

Jubilee time

The Jubilee Session held during the conference was organized to celebrate the 60th birthday of Johann Rafelski, one of the founders of the SQM series and a leading player of the quark–gluon plasma hunting community. His seminal paper "Strangeness Production in the Quark–Gluon Plasma", written together with Berndt Mueller in 1982, triggered worldwide interest in physical observables connected with strangeness.

There was a good reason to celebrate Rafelski's birthday during SQM 2011, since he was born in Krakow. The Jubilee Session included talks given by Andrzej Bialas, Berndt Mueller, Emanuele Quercigh, Joe Kapusta, Marek Gazdzicki, George Stephans, Laszlo Csernai, Tamas Biro and Giorgio Torrieri, and ended with a talk by Rafelski himself.