(Small System) Strangeness Enhancement and Canonical Hadronization Phase Space

For many details I recommend reading the 20 year old text

Hadrons and Quark–Gluon Plasma

Series: Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology (No. 18)

Jean Letessier
Université de Paris VII (Denis Diderot)

Johann Rafelski
University of Arizona

Hardback (ISBN-13: 9780521385367 | ISBN-10: 0521385369) Also available in Paperback | Adobe eBook

Jan Rafelski, CERN-TH-ALICE, June 15, 2018

At CERN: Strangeness a popular QGP signature

I argued 1980-81 that anti-strangeness in QGP can be more abundant than anti-light quarks. Many experiments followed.

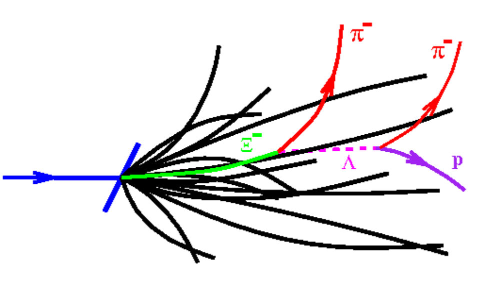
A: There are many strange particles allowing to study different physics questions $(q = u, d)$:

$$K(q\bar{s}),\quad \overline{K}(\bar{q}s),\quad K^*(890),\quad \Lambda(qqs),\quad \overline{\Lambda}(\bar{q}\bar{q}\bar{s}),\quad \Lambda(1520)$$

$$\phi(s\bar{s}),\quad \Xi(qss),\quad \overline{\Xi}(\bar{q}\bar{s}\bar{s}),\quad \Omega(sss),\quad \overline{\Omega}(\bar{s}\bar{s}\bar{s})$$

B: Production rates hence statistical significance is high.

C: Strange hadrons are subject to a self analyzing decay



Instant success:

First strangeness signature 1980: CPOD, WROCLAW, June 2, 2016

ratio of $\bar{s}/\bar{q}$ in $\overline{\Lambda}/\bar{p}$ triggers Marek's strange interest!

What we intend to show is that there are many more $\bar{s}$ quarks than antiquarks of each light flavour. Indeed:

$$\frac{\bar{s}}{\bar{q}} = \frac{1}{2}\left(\frac{m_s}{T}\right)^2 K_2\left(\frac{m_s}{T}\right) e^{\mu/3T} \tag{23}$$

The function $x^2K^2(x)$ is, for example, tabulated in Ref. 15). For $x = m_s/T$ between 1.5 and 2, it varies between 1.3 and 1. Thus, we almost always have more $\bar{s}$ than $\bar{q}$ quarks and, in many cases of interest, $\bar{s}/\bar{q} \sim 5$. As $\mu \to 0$ there are about as many $\bar{u}$ and $\bar{q}$ quarks as there are $\bar{s}$ quarks.

FROM HADRON GAS TO QUARK MATTER II

J. Rafelski

Institut für Theoretische Physik
der Universität Frankfurt

and

R. Hagedorn

CERN--Geneva

Ref.TH.2969-CERN
13 October 1980

ABSTRACT

We describe a quark-gluon plasma in terms of an many questions remain open. A signature of the quark-gluon phase surviving hadronization is suggested.

In *Statistical mechanics of quarks and hadrons* proceedings Bielefeld, August 24-31, 1980

picked up by Marek in Dubna . . .

REFERENCES

1. G.Chapline et al. Phys.Rev., 1975, D8, p. 4302; R.Hagedorn. Preprint CERN, TH. 3207, Geneva, 1981.
2. J.Rafelski. Preprint UFTP, 1982, 80/82 and 86/82; M.I.Grenstein, G.M.Zinovjev. Preprint ITP-82-109E, Moscow 1982.
3. J.W.Harris et al. Phys.Rev.Lett., 1981, 47, p. 229.
4. M.Anikina et al. JINR, P1-82-333, Dubna, 1982.
5. N.Akhababian et al. JINR, D1-82-445, Dubna, 1982.
6. M.Anikina et al. International Conference on Nucleus-Nucleus Collisions, Michigan, 1982, (abstract); E.Okonov. JINR, D2-82-568, Dubna, 1982.
7. A.Abdurakhimov et al. Nucl.Phys., 1981, A362, p. 367.
8. M.Anikina et al. Z.Phys., 1981, C9, p. 105.

Received by Publishing Department
on July, 20, 1983.

4

Anikina M. et al. E1-83-521

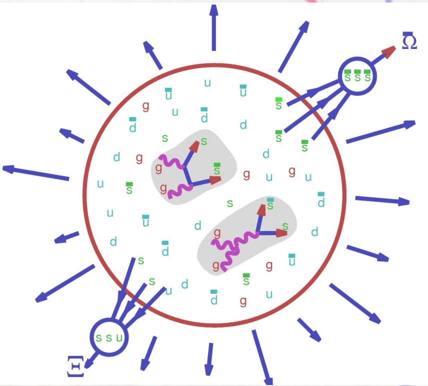
A Study of Λ-Production in Central Nucleus-Nucleus Interactions at a Momentum of 4.5 GeV/c Per Incident Nucleon

Transverse momenta and rapidities of Λ's produ leus-nucleus collisions at 4.5 GeV/c per nucleon /CC , CZr , CPb , OPb/ have been studied and compared with He-Li interactions at the same incident momentum. Pola hyperons was found to be consistent /within the errors/ ($\alpha P_\Lambda = -0.06 \pm 0.11$) for 224 Λ's from central collis of $\bar{\Lambda}/\Lambda$ production ratio was estimated to be less than confidence level.

The analyzed experimental data were obtained usin 2 m streamer spectrometer SKM-200.

The investigation has been performed at the Labora Energies, JINR.

Communication of the Joint Institute for Nuclear Resear

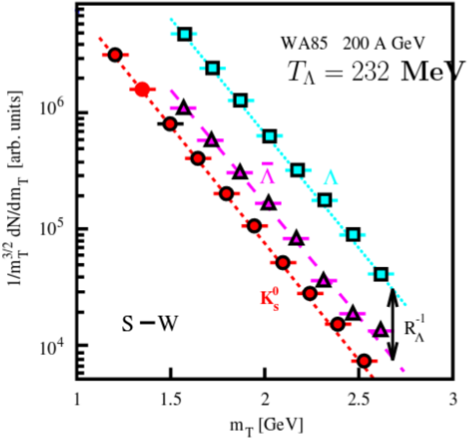


1. $GG \to s\bar{s}$ (thermal gluons collide)
   $GG \to c\bar{c}$ (initial parton collision)
   gluon dominated reactions
2. hadronization of pre-formed
   s, $\bar{s}$, c, $\bar{c}$, b, $\bar{b}$ quarks

Evaporation-recombination formation of complex rarely produced (multi)exotic flavor (anti)particles from QGP is signature of quark mobility thus of deconfinement. Enhancement of flavored (strange, charm,. . .) antibaryons progressing with 'exotic' flavor content. J. Rafelski, *Formation and Observables of the Quark-Gluon Plasma* Phys.Rept. **88** (1982) p331; P. Koch, B. Muller, and J. Rafelski; *Strangeness in Relativistic Heavy Ion Collisions*, Phys.Rept. **142** (1986) p167

Anticipated: Sudden hadronization of QGP
Proposed evidence: matter-antimatter symmetry

High $m_\perp$ slope universality



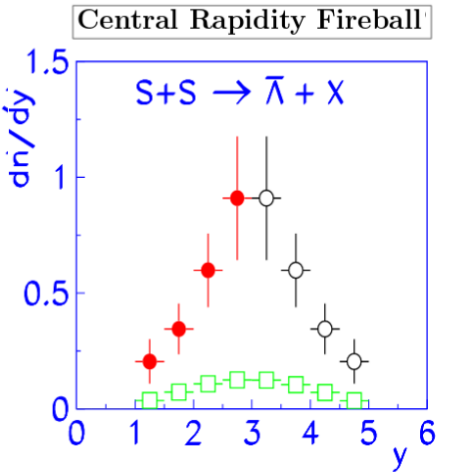
SUDDEN hadronization without rescattering

Discovered in S-Pb collisions by WA85, very pronounced in Pb-Pb Interactions.

Emanuele Quercigh

Why is the slope of baryons and antibaryons the same?

Anticipated: Central QGP fireball
Proposed evidence: (Strange)Antimatter

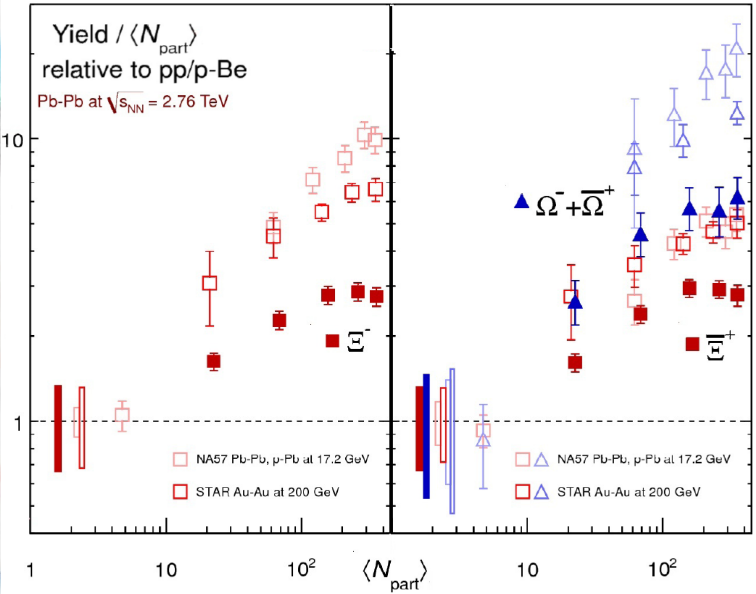


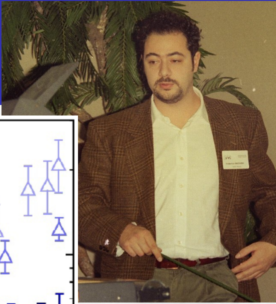
First antibaryon enhancement result, 1990-94, SPS-NA35II EXCESS $\bar{\Lambda}$ emitted from a central well localized source. Background (squares) from multiplicity scaled NN reactions. From Yiota Foka, PhD Thesis, Geneva University 1994.

Conclusion: by early 1990's we have convincing evidence of QGP formation at SPS energy heavy ion collisions including S-S.

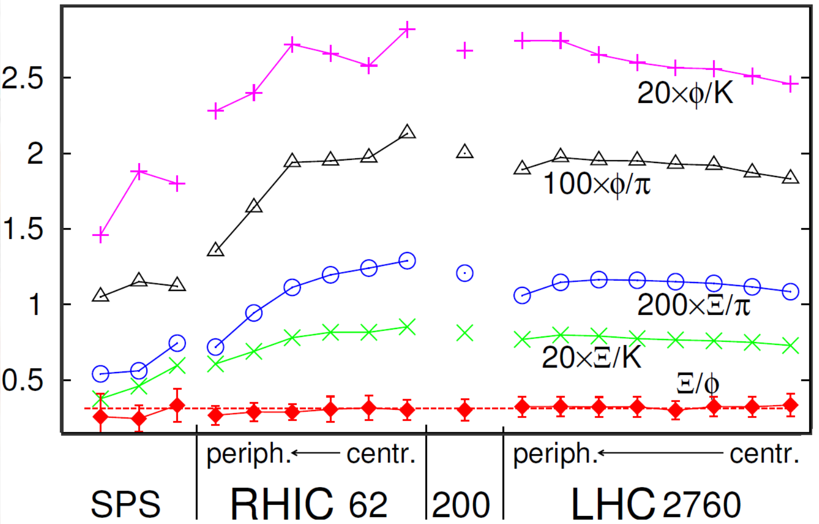
Predicted: Strange antibaryons enhanced

Today: largest medium effect in RHI collisions





$\Xi(ssq)/\phi(s\bar{s})$ (nearly) constant: same production mechanism



M. Petran, J. Rafelski, *Multistrange Particle Production and the Statistical Hadronization Model* Phys.Rev. C **82** (2010) 011901

STATISTICAL HADRONIZATION MODEL... (SHM) WORKS

a) Confinement: $\Longrightarrow$ breakup into free quarks not possible;
b) Strong interaction: $\Longrightarrow$ equal hadron production strength irrespective of produced hadron type
$\Longrightarrow$ 'elementary' hadron yields depend only on the available phase space
Historical approaches:

- Fermi: Micro-canonical phase space
  sharp energy and sharp number of particles
  E. Fermi, Prog.Theor.Phys. 5 (1950) 570: HOWEVER
  Experiments report event-average rapidity particle abundances, model should describe an average event

- Canonical phase space: sharp number of particles
  ensemble average energy $E \to T$ temperature
  T could be, but needs not to be, a kinetic process temperature

- Grand-canonical – ensemble average energy and number of particles:
  $N \to \mu \Leftrightarrow \Upsilon = e^{(\mu/T)}$

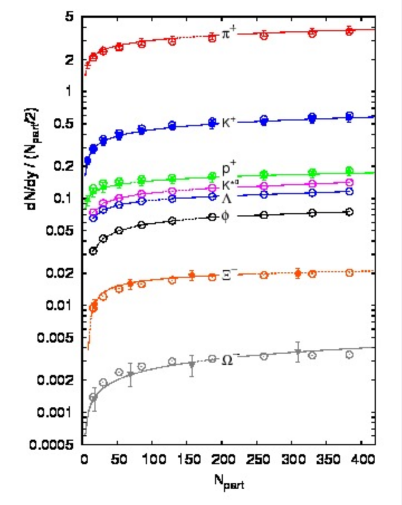
Our interest: bulk QGP fireball properties of hadron source evaluated independent of complex explosion dynamics $\Longrightarrow$ analyze integrated hadron spectra.

SHARE Idea/Team: US-Polish NATO collaboration 2000

Statistical HAadronization with REsonances

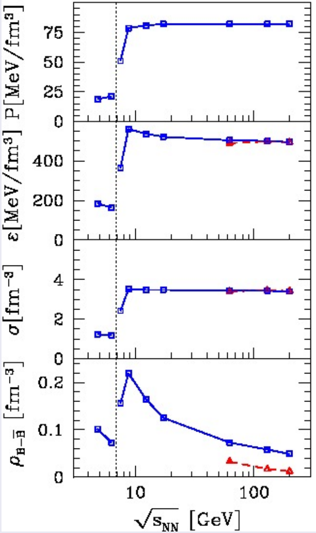
Examples SHM Analysis (Chemical Nonequilibrium)

Particle Yield Example:LHC



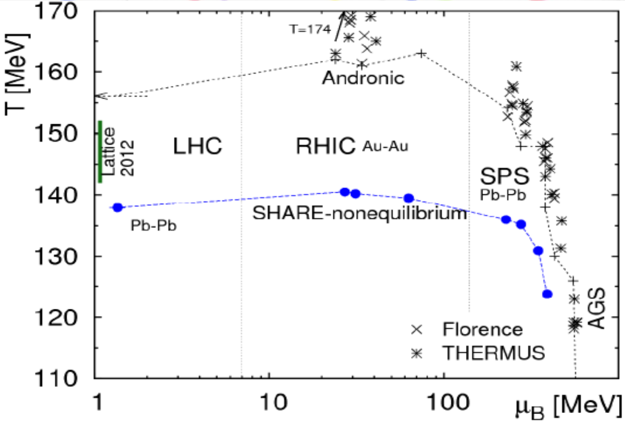
M. Petran, J.Letessier, V. Petracek, J. Rafelski Phys.Rev. C **88** (2013) no.3, 034907

Bulk properties from SHM yields



J. Letessier, J. Rafelski, Eur.Phys.J. A **35** (2008) 221-242

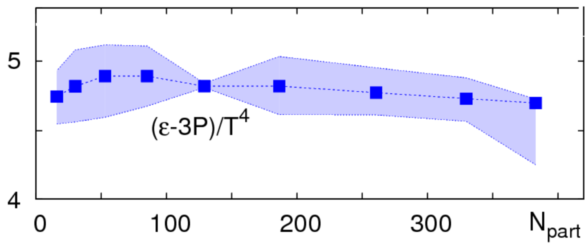
SHARE consistent with lattice QCD Chemical nonequilibrium + supercooling = sudden fireball breakup



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.

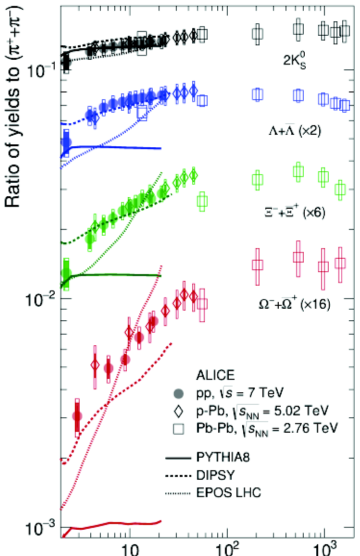
SPS, RHIC, LHC *AA* SHM Digest

- Strange antibaryon signature of QGP: at all energies where data exist there is clear evidence for the same new state of matter. Differences: Volume, Strangeness saturation.
- SHARE based determination of hadronization condition reveals near perfect Universality of fireball bulk properties across the entire reaction energy domain, and L-QCD consistency



- Where we can evaluate: Baryon number deposition varies strongly as function of collision energy. This is the chemical potential dependence on collision energy. WHY? – To clarify question: why no McLerran-Bjorken transparency?

Current interest in small systems:
Strange antibaryon enhancement smoothly rising with entropy of fireball



Nature Physics 2017; doi:10.1038/nphys4111 ALICE

Significant enhancement of strangeness with multiplicity in high multiplicity pp events

pp behavior resamble p-Pb : both in term of value of the ratio and shape

No evident dependence on cms energy: strangeness production apparently driven by final state rather than collision system or energy

At high mult. pp ratio reaches values similar to the one in Pb-Pb (when ratio saturates)

Models fail to riproduce data. Only DIPSY gives a qualitative description.

ALI-PUB-106878

Small particle yield constrained by conservation law: Canonical phase space required

Volume 97B, number 2 PHYSICS LETTERS 1 December 1980

THE IMPORTANCE OF THE REACTION VOLUME IN HADRONIC COLLISIONS

Johann RAFELSKI [1,2]
Institut für Theoretische Physik der Universität, D-6000 Frankfurt/Main, West Germany

and

Michael DANOS
National Bureau of Standards, Washington, DC 20234

Received 10 October 1980

We consider particle production in the frame of the thermodynamic description [1] and explore the physical consequences arising from the conservation of quantum numbers which are conserved exactly

The pair production in the thermodynamic model is shown to depend sensitively on the (hadronic) reaction volume. Strangeness production in nucleus–nucleus collisions is treated as an example.

PHYSICAL REVIEW C VOLUME 31, NUMBER 4 APRIL 1985

Strangeness abundances in $\bar{p}$-nucleus annihilations

C. Derreth and W. Greiner
Institut für Theoretische Physik der Universität Frankfurt, 6000 Frankfurt, Federal Republic of Germany

H.-Th. Elze* and Johann Rafelski
Institute of Theoretical Physics and Astrophysics, University of Cape Town, Rondebosch 7700, Cape Town, South Africa

(Received 27 September 1984)

Strange particle abundances in small volumes of hot hadronic gas are determined in the canonical ensemble with exact strangeness and baryon number conservation. Substantial density and baryon number dependence is found. A $\bar{p}d$ experiment is examined and applications to $\bar{p}$-nucleus annihilations are considered.

Elegant group theory approach for nonabelian charges

Ref.TH.3053-CERN
26 March 1981

Ref.TH.3053-CERN

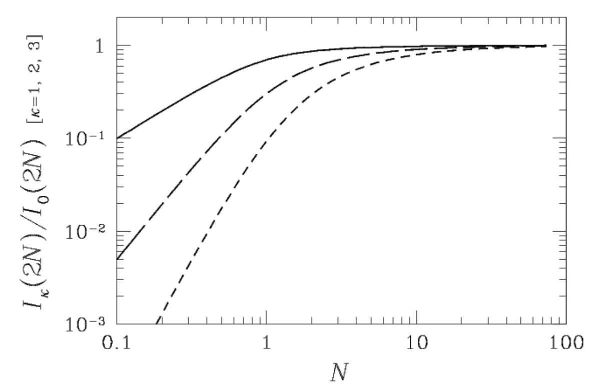
PHASE TRANSITION IN HADRONIC MATTER WITH INTERNAL SYMMETRY *)

K. Redlich **) and L. Turko **)

CERN -- Geneva

ABSTRACT

A general formalism for the description of a thermodynamical system with internal symmetry is introduced. Results are applied to the statistical bootstrap model describing hadronic clusters with isospin conservation taken into account and equations of state are obtained. It is shown that at the sufficiently high energy density, a phase transition occurs. A new phase is an intermediate one between hadronic matter and a quark-gluon plasma phase.



$$\langle N_\kappa^{\mathrm{CE}} \rangle = N_\kappa^{\mathrm{GC}} \frac{I_\kappa(2N_{\mathrm{pair}}^{\mathrm{GC}})}{I_0(2N_{\mathrm{pair}}^{\mathrm{GC}})}.$$

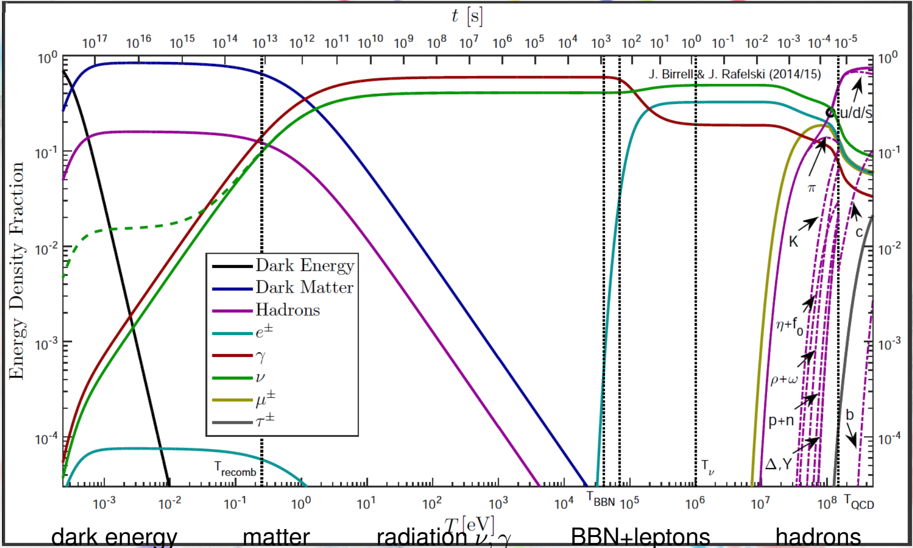
Canonical yield-suppression factors I_κ/I_0 as function of the grand-canonical pair yield N. Short-dashed line: the suppression of triply-strange-flavored hadrons; long-dashed line: the suppression of doubly-strange-flavored hadrons; and solid line, the suppression of singly-strange-flavored hadrons.

A few first analysis observations and summary

- We performed a few hobby (lack of resources) analysis of the ALICE small system results and there is evidence that in addition to the growth γ_s of strangeness yield with size of the system there is canonical phase space required as was expected. Effects are not overwhelming but noticeable.
- Hadronization conditions seems a few MeV higher compared to large systems: conclusion there is no supercooling, less explosive expansion.
- Corresponding bulk matter properties are higher. No test of universal hadronization / conformal anomaly was performed.
- Small system flavor content universally zero (and it seems we are sensitive due to small system): there is no electric charge, etc. So a few (more than one) canonical constraints need to be implemented. Maybe Bjorken model (scaling solution) works for ALICE pp results.

No systematic effort to prove any of this was undertaken (lack of resources).

The Universe Composition in Single View



Different dominance eras: Temperature grows to right