FACES

of

QUARK MATTER

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TIME EVOLUTION OF HEAVY ION COLL.

incident partons are coherent

PRIMARY COLLISION BETWEEN PARTONS

partons are incoherent $\searrow$ final state

$\Downarrow$

? evolution of masless quark-gluon matter?

$\Downarrow$

PRODUCTION OF HOT VALON MATTER

$\Downarrow$

EVOLUTION OF VALON MATTER

$\Downarrow$

HADRONIZATION OF VALON MATTER

$\Downarrow$ $\Downarrow$

evolution of hadron matter final state

$\Downarrow$

final state

At very final state the resonances decay

QUALITATIVE CONSIDERATIONS

- Concept of LOSS OF SMALL MOMENTUM PARTONS in first collision (V.N. Gribov)

- Compare with WOUNDED NUCLEON model (A.Bialas)

- $\rightarrow$ soft, semihard, hard and thermal collisions

- Compare with VALON m_t DISTRIBUTION (P.Lévai)

- Are the STRANGE - ANTISTRANGE pairs PRODUCED in the PRIMARY collisions ?

- Then $S, \overline{S}$ ENHANCEMENT IS NOT SIGNATURE for appearence of quark gluon plasma

- BUT THE FREE RECOMBINATION OF VALONS IS A SIGNATURE FOR THE FORMATION OF DECONFINED QUARK-ANTIQUARK MATTER

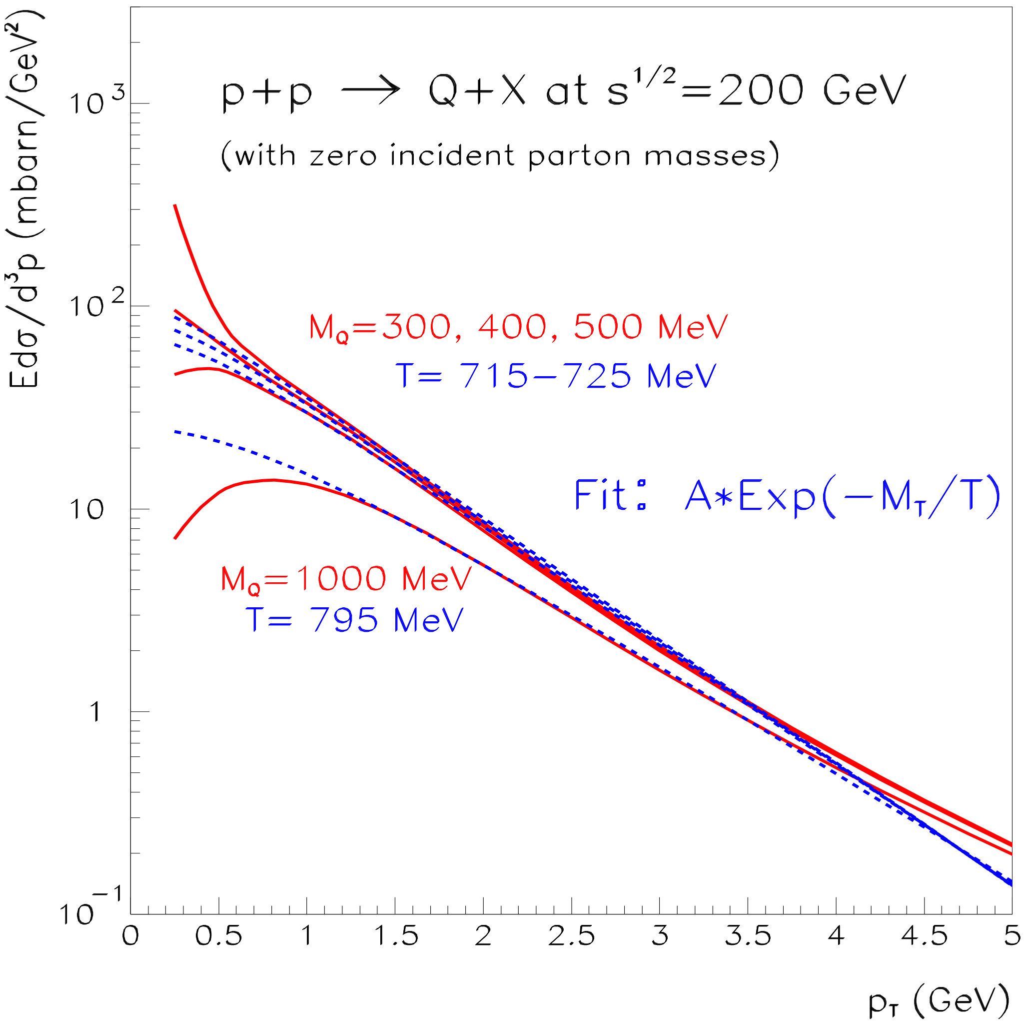

Figure 1: Invariant transverse momentum spectra of massive quark (valon) produced in $p + p$ reaction at $\sqrt{s} = 200$ GeV. The incident parton masses are zero, the produced quarks are heavy with effective masses $M_Q = 300, 400, 500, 1000$ MeV. Figure is from *P. Levai, Heavy Ion Phys. 5 (1997) 239.*.

OTHER APPROACHES

- at the collision of very high energy nuclei the gluon density is so high, that something like a mean field is produced, and these mean fields collide to produce even more gluons (L. McLeran)

- the gluon density saturates and thus the produced gluon density will have a lower value (K. Eskola)

- new quark-antiquark pairs are produced during the hadronization (Nambu-Jona-Lasinio)

THE BIRTH OF QUARK MATTER

PREHISTORY, BELIEFS

- QGP of zero mass quarks, antiquarks, gluons
- First order phase transition, quasistatic, Gibbs criteria
- Homogeneous distributions, single μ_q, μ_s, T

- ALL THESE IDEAS ARE KILLED BY THE NEW OBSERVATIONS

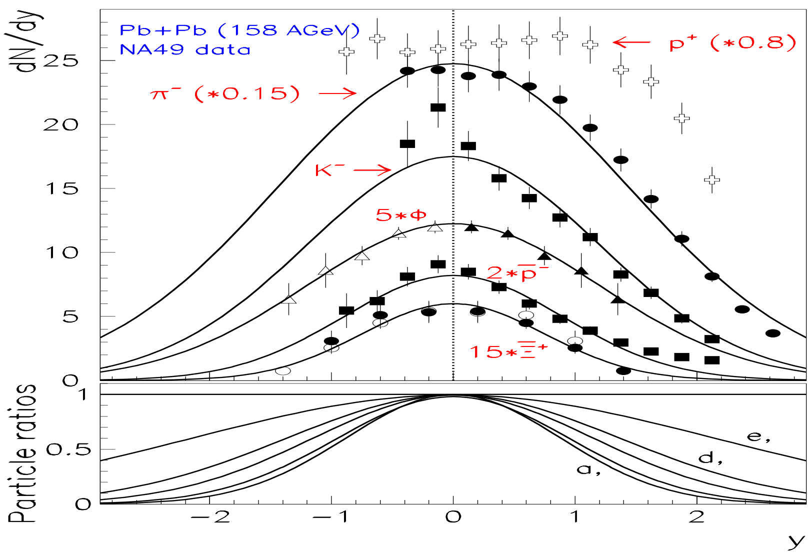

Figure 2: Top panel: Normalized rapidity spectra of hadrons produced in Pb+Pb collision at $E_{LAB} = 158$ A GEV. Data are from NA49. Bottom panel: particle ratios normalized to unity at the mid-rapidity. The lines indicate: a, $\overline{\Xi}^{+}/K^{-}$; b, $\overline{\Xi}^{+}/\Phi$; c, $\overline{p}^{-}/\pi^{-}$; d, $\overline{p}^{-}/K^{-}$; e, Φ/π^{-}.

BRAHMS: $\overline{p}/p = 0.64(y=0), 0.41(y=2)$

What is the way out?

The solution to this problem

ALCOR

ALgebraic COalescence Rehadronization

with P. Lévai and T.S. Biró and T. Csörgö

Hadron ratios at midrapidity at RHIC

The baryon nunbers are proportional to the number of quarks from which they consist.

$$\begin{aligned} p &= C_{\mathrm{p}}\, b_{\mathrm{q}}\, b_{\mathrm{q}}\, b_{\mathrm{q}}\, q\, q\, q \\ \Lambda &= C_{\Lambda}\, b_{\mathrm{q}}\, b_{\mathrm{q}}\, b_{\mathrm{s}}\, q\, q\, s \\ \Xi &= C_{\Xi}\, b_{\mathrm{q}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, q\, s\, s \\ \Omega &= C_{\Omega}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, s\, s\, s \end{aligned} \tag{1}$$

We obtain similarly the antibaryons:

$$\begin{aligned} \overline{p} &= C_{\overline{p}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{q}}}\, \overline{q}\, \overline{q}\, \overline{q} \\ \overline{\Lambda} &= C_{\overline{\Lambda}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{s}}}\, \overline{q}\, \overline{q}\, \overline{s} \\ \overline{\Xi} &= C_{\overline{\Xi}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{q}\, \overline{s}\, \overline{s} \\ \overline{\Omega} &= C_{\overline{\Omega}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{s}\, \overline{s}\, \overline{s} \end{aligned} \tag{2}$$

Finally the mesons:

$$\begin{aligned} \pi &= C_{\pi}\, b_{\mathrm{q}}\, b_{\overline{\mathrm{q}}}\, q\, \overline{q} \\ K &= C_{K}\, b_{\mathrm{q}}\, b_{\overline{\mathrm{s}}}\, q\, \overline{s} \\ \overline{K} &= C_{\overline{K}}\, b_{\overline{\mathrm{q}}}\, b_{\mathrm{s}}\, \overline{q}\, s \\ \eta &= C_{\eta}\, b_{\overline{\mathrm{s}}}\, b_{\mathrm{s}}\, \overline{s}\, s \end{aligned} \tag{3}$$

Here the normalization coefficients, $b_{\rm i}$, are determined uniquely by the requirement, that

the number of the constituent quarks do not change during the hadronization

thus we have 4 (6 , if u and d are treated separately) conserved quantity in contrast to the 2 parameters μ_{baryon}, $\mu_{strange}$ of the thermal models

This is the basic assumption for all quark counting methods

$$
\begin{aligned}
s &= 3\,\Omega + 2\,\Xi + \Lambda + \overline{K} + \eta \\
\overline{s} &= 3\,\overline{\Omega} + 2\,\overline{\Xi} + \overline{\Lambda} + K + \eta \\
q &= 3\,p + \Xi + 2\,\Lambda + K + \pi \\
\overline{q} &= 3\,\overline{p} + \overline{\Xi} + 2\,\overline{\Lambda} + \overline{K} + \pi\ .
\end{aligned} \tag{4}
$$

The consequences of the simplified equations

assumption : $C_x = C_{\overline{x}}$

$$
\begin{aligned}
\frac{\overline{p}}{p} &= \frac{b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{q}}}\, \overline{q}\, \overline{q}\, \overline{q}}{b_{\mathrm{q}}\, b_{\mathrm{q}}\, b_{\mathrm{q}}\, q\, q\, q} \\
\frac{\overline{\Lambda}}{\Lambda} &= \frac{b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{s}}}\, \overline{q}\, \overline{q}\, \overline{s}}{b_{\mathrm{q}}\, b_{\mathrm{q}}\, b_{\mathrm{s}}\, q\, q\, s} = \frac{b_{\mathrm{q}}\, b_{\overline{\mathrm{s}}}\, q\, \overline{s}}{b_{\overline{\mathrm{q}}}\, b_{\mathrm{s}}\, \overline{q}\, s} \cdot \frac{\overline{p}}{p} \\
\frac{\overline{\Xi}}{\Xi} &= \frac{b_{\overline{\mathrm{q}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{q}\, \overline{s}\, \overline{s}}{b_{\mathrm{q}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, q\, s\, s} = \frac{b_{\mathrm{q}}\, b_{\overline{\mathrm{s}}}\, q\, \overline{s}}{b_{\overline{\mathrm{q}}}\, b_{\mathrm{s}}\, \overline{q}\, s} \cdot \frac{\overline{\Lambda}}{\Lambda} \\
\frac{\overline{\Omega}}{\Omega} &= \frac{b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{s}\, \overline{s}\, \overline{s}}{b_{\mathrm{s}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, s\, s\, s} = \frac{b_{\mathrm{q}}\, b_{\overline{\mathrm{s}}}\, q\, \overline{s}}{b_{\overline{\mathrm{q}}}\, b_{\mathrm{s}}\, \overline{q}\, s} \cdot \frac{\overline{\Xi}}{\Xi}
\end{aligned}
\tag{5}
$$

$$
D = \frac{b_{\mathrm{q}}\, b_{\overline{\mathrm{s}}}\, q\, \overline{s}}{b_{\overline{\mathrm{q}}}\, b_{\mathrm{s}}\, \overline{q}\, s} = \frac{K}{\overline{K}}
\tag{6}
$$

Thus one can write eq.5 in the simple form

$$
\begin{aligned}
\frac{\overline{\Lambda}}{\Lambda} &= D \cdot \frac{\overline{p}}{p} \\
\frac{\overline{\Xi}}{\Xi} &= D \cdot \frac{\overline{\Lambda}}{\Lambda} \\
\frac{\overline{\Omega}}{\Omega} &= D \cdot \frac{\overline{\Xi}}{\Xi}
\end{aligned}
\tag{7}
$$

ALCOR: Quark Combinatorics in Rehadronization: the effect of isospin asymetry

Coalescence equations without isospin symetry

Relax the isospin symmetry assumption and treat separately the u and d quarks.

The coalescence equations for the flavour clusters now read:

$$
\begin{aligned}
p^{+} &= C_{\mathrm{p}}\, b_{\mathrm{u}}\, b_{\mathrm{u}}\, b_{\mathrm{d}}\, u\, u\, d \\
n^{0} &= C_{\mathrm{n}}\, b_{\mathrm{u}}\, b_{\mathrm{d}}\, b_{\mathrm{d}}\, u\, d\, d \\
\Lambda^{0} &= C_{\Lambda}\, b_{\mathrm{u}}\, b_{\mathrm{d}}\, b_{\mathrm{s}}\, u\, d\, s \\
\Sigma^{+} &= C_{\Sigma^{+}}\, b_{\mathrm{u}}\, b_{\mathrm{u}}\, b_{\mathrm{s}}\, u\, u\, s \\
\Sigma^{-} &= C_{\Sigma^{-}}\, b_{\mathrm{d}}\, b_{\mathrm{d}}\, b_{\mathrm{s}}\, d\, d\, s \\
\Xi^{0} &= C_{\Xi^{0}}\, b_{\mathrm{u}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, u\, s\, s \\
\Xi^{-} &= C_{\Xi^{-}}\, b_{\mathrm{d}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, d\, s\, s \\
\Omega^{-} &= C_{\Omega}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, s\, s\, s
\end{aligned}
\tag{8}
$$

and similar equations for antibaryons.

The equations for the mesons:

$$
\begin{aligned}
\pi^+ &= C_{\pi^+}\, b_{\mathrm{u}}\, b_{\overline{\mathrm{d}}}\, u\, \overline{d} \\
\pi^0 &= C_{\pi^0}\, (b_{\mathrm{u}}\, b_{\overline{\mathrm{u}}}\, u\, \overline{u} + b_{\mathrm{d}}\, b_{\overline{\mathrm{d}}}\, d\, \overline{d})/2 \\
\pi^- &= C_{\pi^-}\, b_{\mathrm{d}}\, b_{\overline{\mathrm{u}}}\, d\, \overline{u} \\
K^+ &= C_{K^+}\, b_{\mathrm{u}}\, b_{\overline{\mathrm{s}}}\, u\, \overline{s} \\
K^- &= C_{K^-}\, b_{\overline{\mathrm{u}}}\, b_{\mathrm{s}}\, \overline{u}\, s \\
K^0 &= C_{K^0}\, b_{\mathrm{d}}\, b_{\overline{\mathrm{s}}}\, d\, \overline{s} \\
\overline{K}^0 &= C_{\overline{K}^0}\, b_{\overline{\mathrm{d}}}\, b_{\mathrm{s}}\, \overline{\mathrm{d}}\;\, s \\
\eta &= C_{\eta}\, b_{\overline{\mathrm{s}}}\, b_{\mathrm{s}}\, \overline{s}\, s \\
\eta' &= C_{\eta'}\, (b_{\mathrm{u}}\, b_{\overline{\mathrm{u}}}\, u\, \overline{u} + b_{\mathrm{d}}\, b_{\overline{\mathrm{d}}}\, d\, \overline{d})/2 \qquad (9)
\end{aligned}
$$

Here again the normalization coefficients, b_{i}, are determined uniquely by the quark number conservation demand.

The equations for the quark and antiquark number conservation:

$$
\begin{aligned}
u &= 2p^{+} + n^{0} + \Lambda^{0} + 2\Sigma^{+} + \Xi^{0} + \pi^{+} + (\pi^{0} + \eta')/2 + K^{+} \\
\overline{u} &= 2\overline{p}^{-} + \overline{n}^{0} + \overline{\Lambda}^{0} + 2\overline{\Sigma}^{-} + \overline{\Xi}^{0} + \pi^{-} + (\pi^{0} + \eta')/2 + K^{-} \\
d &= 2n^{0} + p^{+} + \Lambda^{0} + 2\Sigma^{-} + \Xi^{-} + \pi^{-} + (\pi^{0} + \eta')/2 + K^{0} \\
\overline{d} &= 2\,\overline{n}^{0} + \overline{p}^{-} + \overline{\Lambda}^{0} + 2\overline{\Sigma}^{+} + \overline{\Xi}^{+} + \pi^{+} + (\pi^{0} + \eta')/2 + \overline{K}^{0} \\
s &= 3\Omega^{-} + 2\Xi^{-} + 2\Xi^{0} + \Lambda^{0} + \Sigma^{+} + \Sigma^{-} + \overline{K}^{0} + K^{-} + \eta \\
\overline{s} &= 3\overline{\Omega}^{+} + 2\overline{\Xi}^{+} + 2\overline{\Xi}^{0} + \overline{\Lambda}^{0} + \overline{\Sigma}^{-} + \overline{\Sigma}^{+} + K^{0} + K^{+} + \eta
\end{aligned}
\tag{10}
$$

In eq. (10) π is the number of directly produced pions.

(Most of the observed pions are created in the decay of resonances.)

Consequences of the extended equations

$$
\begin{aligned}
\frac{\overline{p}}{p} &= \frac{b_{\overline{\mathrm{u}}}\, b_{\overline{\mathrm{u}}}\, b_{\overline{\mathrm{d}}}\, \overline{u}\, \overline{u}\, \overline{d}}{b_{\mathrm{u}}\, b_{\mathrm{u}}\, b_{\mathrm{d}}\, u\, u\, d} \\
\frac{\overline{\Lambda}}{\Lambda} &= \frac{b_{\overline{\mathrm{u}}}\, b_{\overline{\mathrm{d}}}\, b_{\overline{\mathrm{s}}}\, \overline{u}\, \overline{d}\, \overline{s}}{b_{\mathrm{u}}\, b_{\mathrm{d}}\, b_{\mathrm{s}}\, u\, d\, s} = \frac{b_{\mathrm{u}}\, b_{\overline{\mathrm{s}}}\, u\, \overline{s}}{b_{\overline{\mathrm{u}}}\, b_{\mathrm{s}}\, \overline{u}\, s} \cdot \frac{\overline{p}}{p} \\
\frac{\overline{\Xi}^0}{\Xi^0} &= \frac{b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{u}\, \overline{s}\, \overline{s}}{b_{\mathrm{u}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, u\, s\, s} = \frac{b_{\mathrm{d}}\, b_{\overline{\mathrm{s}}}\, d\, \overline{s}}{b_{\overline{\mathrm{d}}}\, b_{\mathrm{s}}\, \overline{d}\, s} \cdot \frac{\overline{\Lambda}}{\Lambda} \\
\frac{\overline{\Xi}^+}{\Xi^-} &= \frac{b_{\overline{\mathrm{d}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{d}\, \overline{s}\, \overline{s}}{b_{\mathrm{d}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, d\, s\, s} = \frac{b_{\mathrm{u}}\, b_{\overline{\mathrm{s}}}\, u\, \overline{s}}{b_{\overline{\mathrm{u}}}\, b_{\mathrm{s}}\, \overline{u}\, s} \cdot \frac{\overline{\Lambda}}{\Lambda} \\
\frac{\overline{\Omega}}{\Omega} &= \frac{b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, b_{\overline{\mathrm{s}}}\, \overline{s}\, \overline{s}\, \overline{s}}{b_{\mathrm{s}}\, b_{\mathrm{s}}\, b_{\mathrm{s}}\, s\, s\, s} = \frac{b_{\mathrm{d}}\, b_{\overline{\mathrm{s}}}\, d\, \overline{s}}{b_{\overline{\mathrm{d}}}\, b_{\mathrm{s}}\, \overline{d}\, s} \cdot \frac{\overline{\Xi}^+}{\Xi^-} \qquad (11)
\end{aligned}
$$

Let us introduce the notations:

$$
\begin{aligned}
B &= \frac{b_{\mathrm{d}}\, b_{\overline{\mathrm{s}}}\, d\, \overline{s}}{b_{\overline{\mathrm{d}}}\, b_{\mathrm{s}}\, \overline{d}\, s} = \frac{K^0}{\overline{K}^0} \\
D &= \frac{b_{\mathrm{u}}\, b_{\overline{\mathrm{s}}}\, u\, \overline{s}}{b_{\overline{\mathrm{u}}}\, b_{\mathrm{s}}\, \overline{u}\, s} = \frac{K^+}{K^-} \\
C &= \frac{B}{D} = \frac{K^0/\overline{K}^0}{K^+/K^-} \qquad (12)
\end{aligned}
$$

$$
\begin{aligned}
\frac{\overline{\Lambda}^0}{\Lambda^0} &= D \cdot \frac{\overline{p}^-}{p^+} \\
\frac{\overline{\Xi}^0}{\Xi^0} &= C \cdot D \cdot \frac{\overline{\Lambda}^0}{\Lambda^0} \\
\frac{\overline{\Xi}^+}{\Xi^-} &= D \cdot \frac{\overline{\Lambda}^0}{\Lambda^0} \\
\frac{\overline{\Omega}^+}{\Omega^-} &= C \cdot D \cdot \frac{\overline{\Xi}^+}{\Xi^-}
\end{aligned}
\tag{13}
$$

The correction factor C shows the effect of isospin. For a system with equal number of neutros and protons $C = 1$. For other cases it can be obtained by inserting the exprimental values into the defining equation, eq.(13), or calculating it from a model. In the ALCOR $C = 1.0$ due to symmetries.

Addendum: in the complet ALCOR calculation the rezonances belonging to the two lowest baryon multiplets and to the lowest two meson multiplets are also included.

Comparison of experimental data with the parameterfree predictions of ALCOR

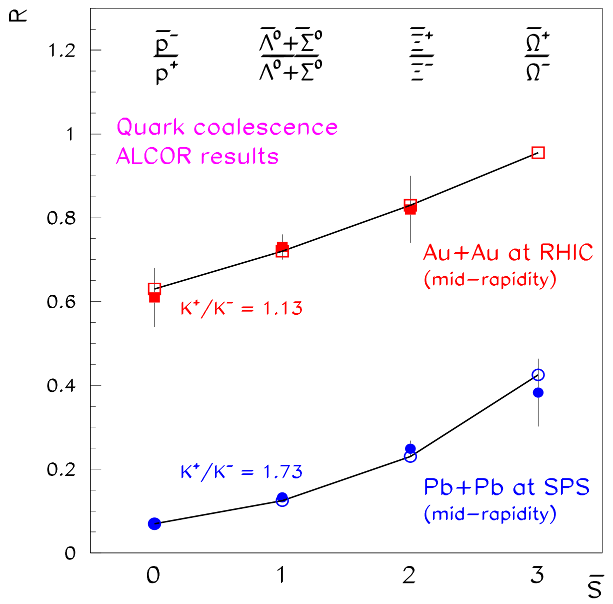

Figure 3: Calculated (open symbols) and measured (full symbols) hyperon ratios for SPS(WA97) and RHIC(STAR) experiments.

see also Van Buren

THE FULL ALCOR CALCULATION

For the full calculation we have to define three input parameters.

These we obtain as follows.

From the fit to the

number of π^- $\rightarrow$ number of $q\overline{q}$ pairs

number of K^- $\rightarrow$ strange ratio: f_s (Wroblinski factor)

ratio K^+/K^- $\rightarrow$ stopping: percentage of incident quarks stopped into the investigated rapidity interval

Comparison of experimental data with other predictions of ALCOR

Choosing 197 newly produced $u\overline{u}$ and $d\overline{d}$ pairs (this means 86 $s\overline{s}$ pairs) and assuming that 5 % of the total nucleon numbers stopped into the central unit of rapidity (which means 8 proton and 12 neutron), we can calculate the measured rapidity densities and hadronic ratios for the Au+Au collision at $\sqrt{s} = 130$ AGeV in the central rapidity as displayed in Table 1.

	ALCOR model	Preliminary data	Ref.
h^-	260	264 ± 18	STAR (4)
K^+/π^+	0.142	0.15 ± 0.01	STAR (13)
K^+/K^-	1.13	1.12 ± 0.06	STAR (4)
Ξ^-/π^-	0.015	0.014 ± 0.01	STAR (5)
$\overline{p}^-/p^+$	0.63	0.61 ± 0.06	STAR (4)
$\overline{\Lambda}/\Lambda$	0.72	0.73 ± 0.03	STAR (4)
$\overline{\Xi}^+/\Xi^-$	0.83	0.82 ± 0.08	STAR (4)
K^{*+}/h^-	0.077	0.065	STAR (4)
$\overline{K}^{*-}/h^-$	0.067	0.060	STAR (4)

Table 1: Hadron production in Au+Au collision at $\sqrt{s} = 130$ AGeV from the ALCOR model and the preliminary experimental data [4,13]

Energy dependence of physical quantities obtained from experimetal data by ALCOR

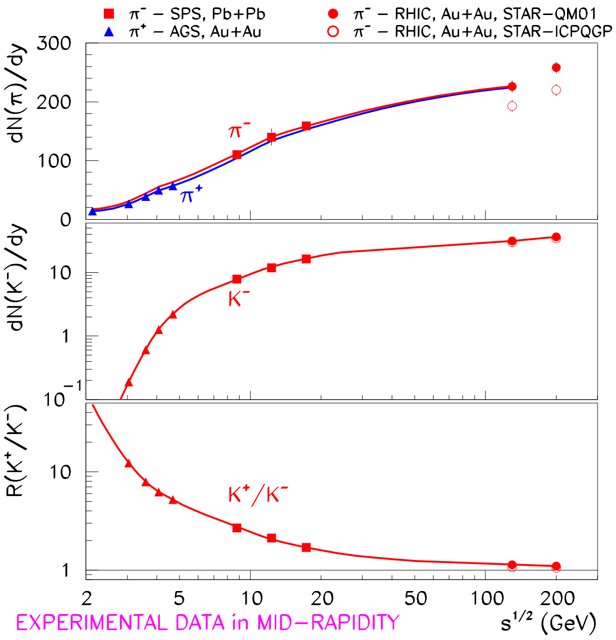

Figure 4: The three measured input data for ALCOR as a function of energy. Date from AGS, SPS, RHIC experiments.

- From the fit of ALCOR output
- to the experimental data displayed in the three panel we obtain
- the three physical input parameters of ALCOR.

From the fit to the

number of π^- $\longrightarrow$ number of $q\overline{q}$ pairs

number of K^- $\longrightarrow$ strange ratio: f_s

ratio K^+/K^- $\longrightarrow$ stopping: percentage of incident quarks stopped into the investigated rapidity interval

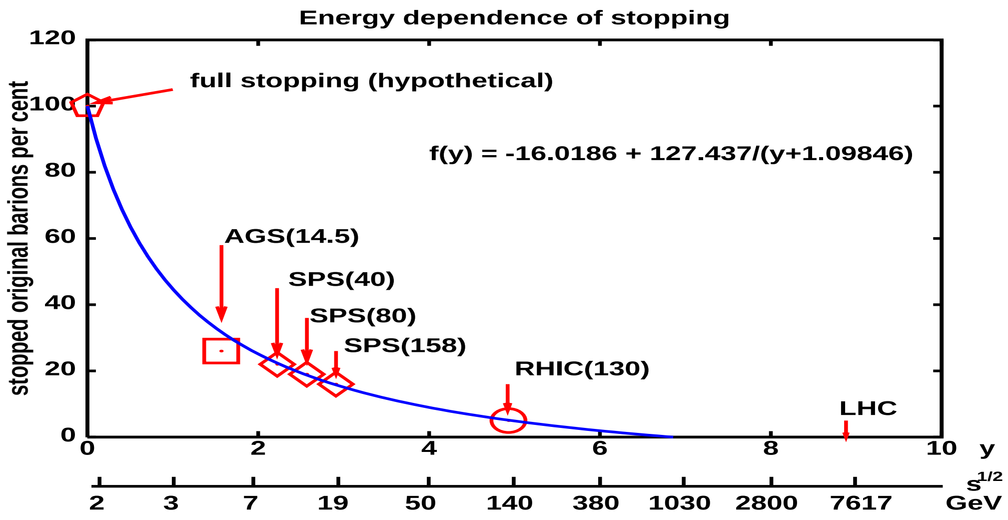

Figure 5: Stopping

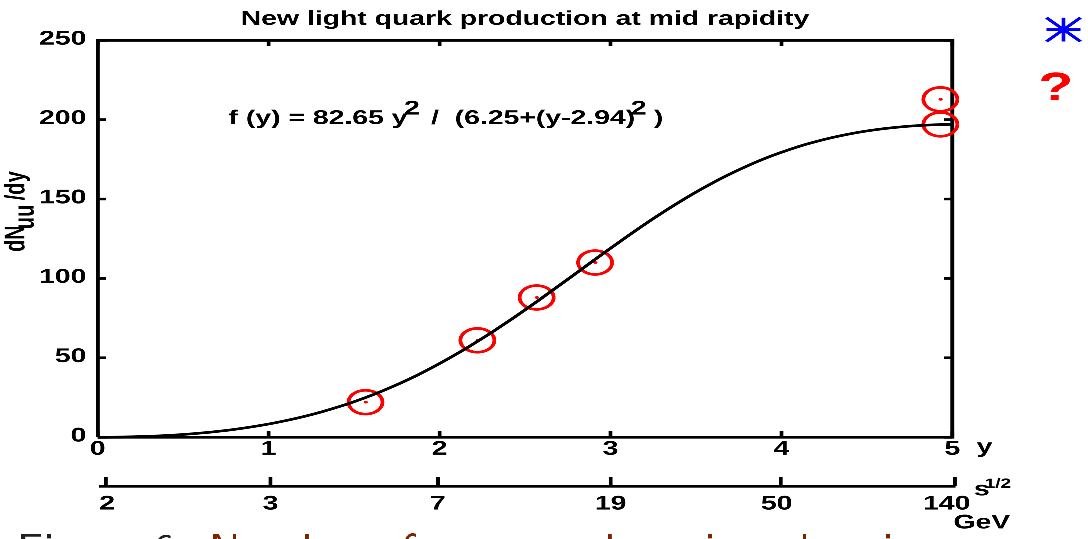

Figure 6: Number of new quark antiquark pairs

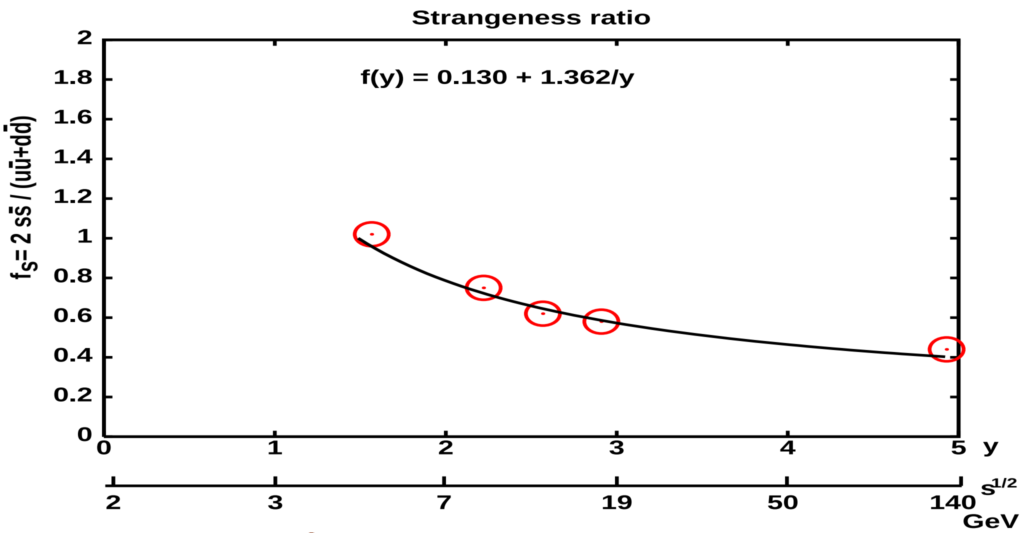

Figure 7: Ratio of strange to non strange quark pairs

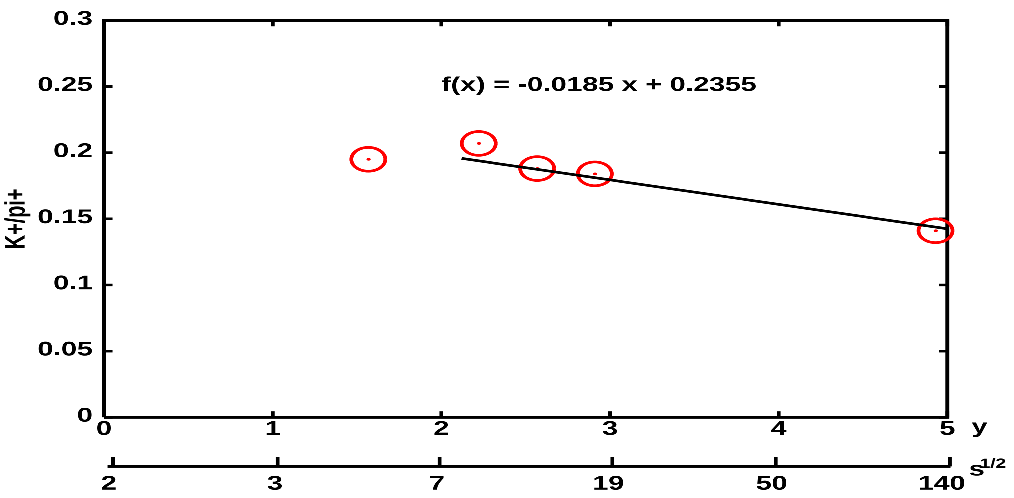

Figure 8: Kaon to pion ratios

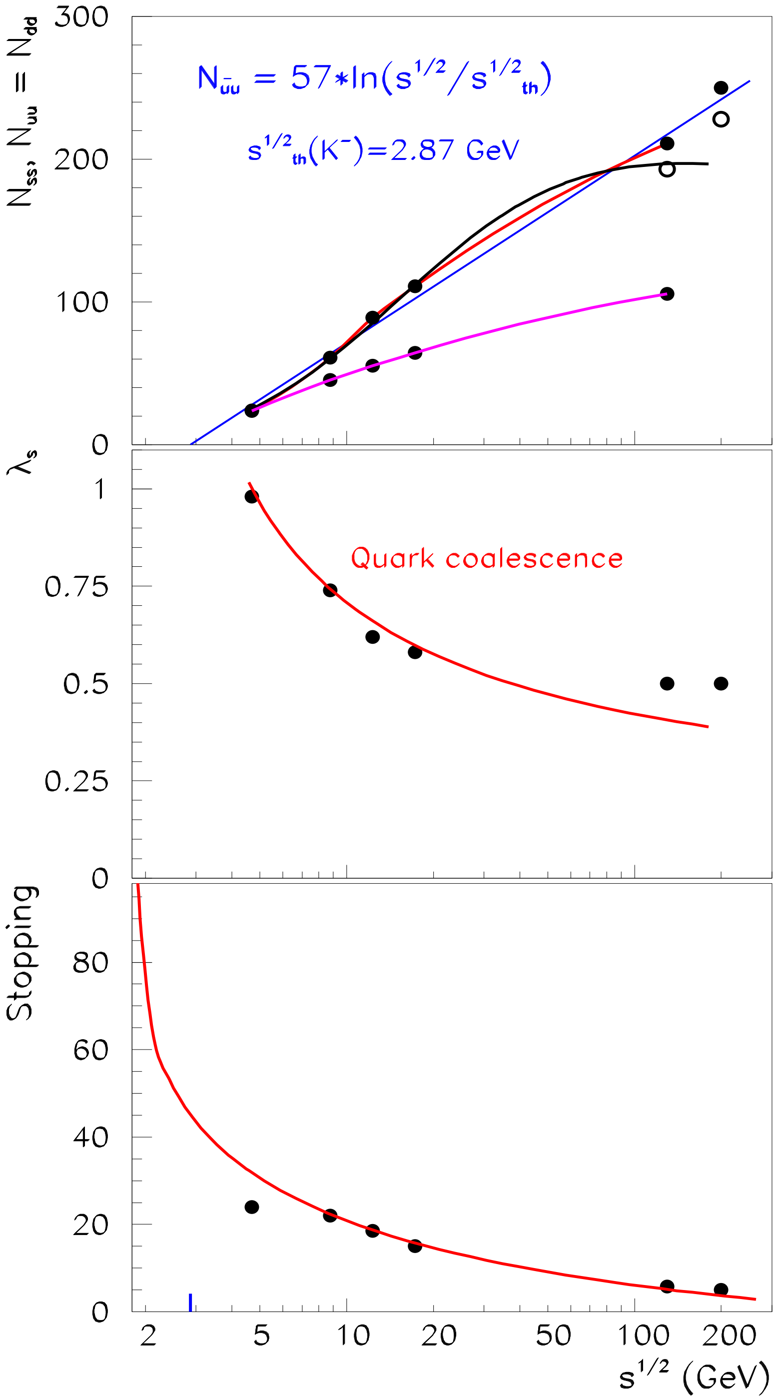

Figure 9: Fits in other representations

CONCLUSION

we were on the quest of

QUARK GLUON PLASMA

and we found the

CONSTITUENT

QUARK-ANTIQUARK MATTER

- we transformed the measured particle numbers into physical quantities with the help of ALCOR

- at RHIC we are near to the complete transparency and it may be reached before LHC energy

- at RHIC we are near to the maximal prehadronization energy density (see number of new midrapidity $q, \overline{q}$ pairs) or we shall meet something new

- are the $q, \overline{q}$ pairs produced with two or more mechanism which have different energy dependence? (behaviour of f_s)