Transition from Baryonic to Mesonic Freeze-Out.

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Outline

Chemical Equilibrium

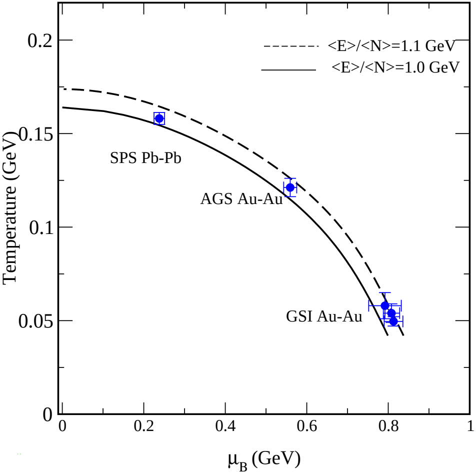
Comparison of Chemical Freeze-Out Criteria

If everything is smooth why is there such a roller-coaster in the particle ratios?

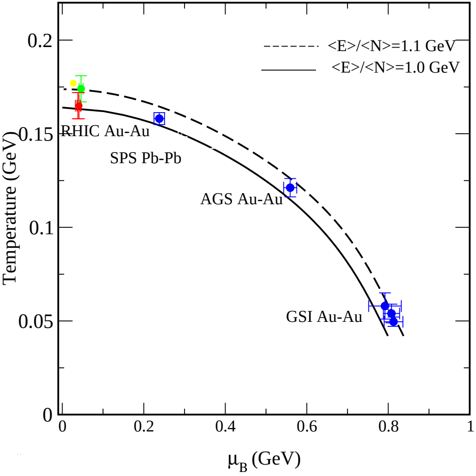
The Horn

Summary

E/N in 1999

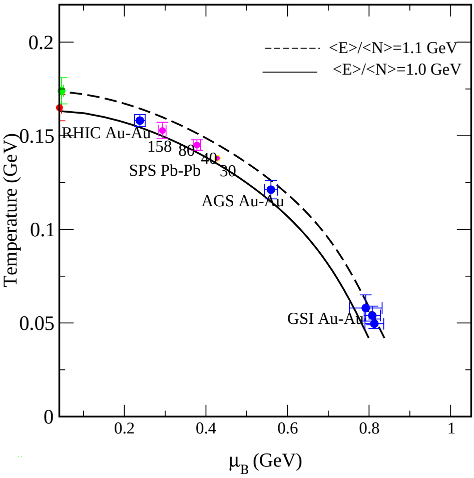

<E>/<N>=1.1 GeV
<E>/<N>=1.0 GeV
SPS Pb-Pb
AGS Au-Au
GSI Au-Au
Temperature (GeV)
μ_B (GeV)
0
0.05
0.1
0.15
0.2
0
0.2
0.4
0.6
0.8
1

E/N in 2000



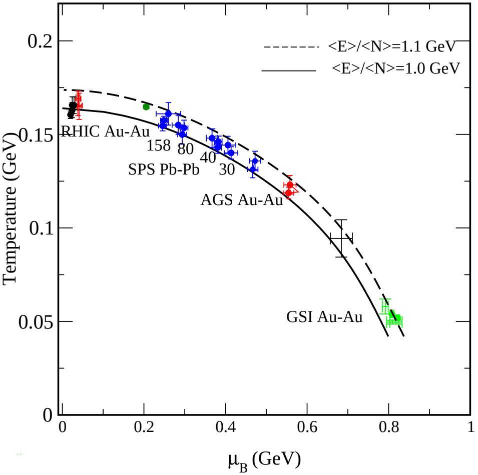
<E>/<N>=1.1 GeV
<E>/<N>=1.0 GeV
RHIC Au-Au
SPS Pb-Pb
AGS Au-Au
GSI Au-Au
Temperature (GeV)
0
0.05
0.1
0.15
0.2
0
0.2
0.4
0.6
0.8
1
μ_B (GeV)

E/N in 2005



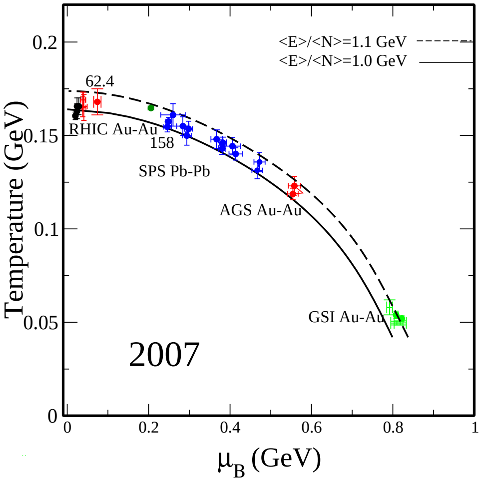
<E>/<N>=1.1 GeV
<E>/<N>=1.0 GeV
RHIC Au-Au
158
80
40
30
SPS Pb-Pb
AGS Au-Au
GSI Au-Au
Temperature (GeV)
μB (GeV)
0.2
0.15
0.1
0.05
0
0.2
0.4
0.6
0.8
1

E/N in 2005

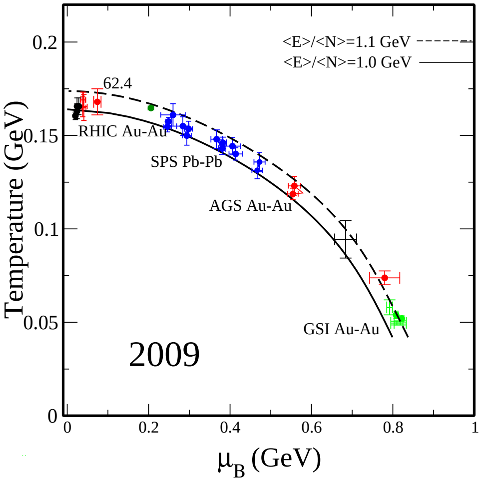


A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772, 167, 2006
J. Manninen, F. Becattini, M, Gazdzicki, Phys. Rev. C73 044905, 2006
R. Picha, U of Davis, Ph.D. thesis 2002

E/N in 2007

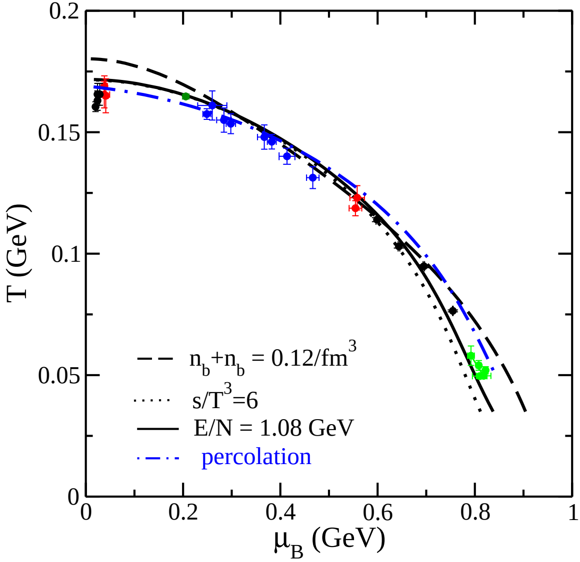

<E>/<N>=1.1 GeV
<E>/<N>=1.0 GeV
62.4
RHIC Au-Au
158
SPS Pb-Pb
AGS Au-Au
GSI Au-Au
2007
Temperature (GeV)
0.2
0.15
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1
μB (GeV)

E/N in 2009

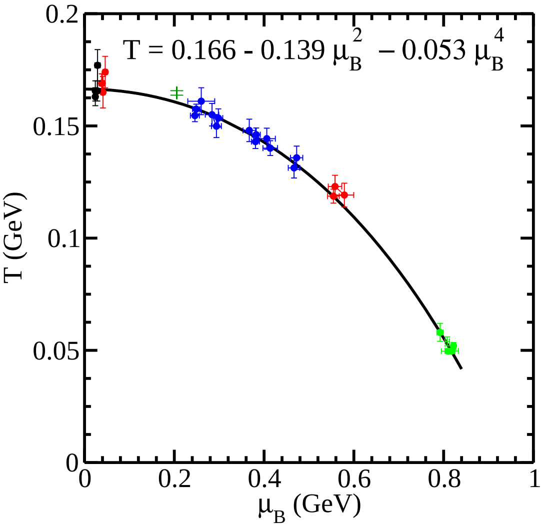


<E>/<N>=1.1 GeV
<E>/<N>=1.0 GeV
62.4
RHIC Au-Au
SPS Pb-Pb
AGS Au-Au
GSI Au-Au
2009
Temperature (GeV)
0
0.05
0.1
0.15
0.2
0
0.2
0.4
0.6
0.8
1
μ_B (GeV)

Chemical Freeze-Out: Criteria

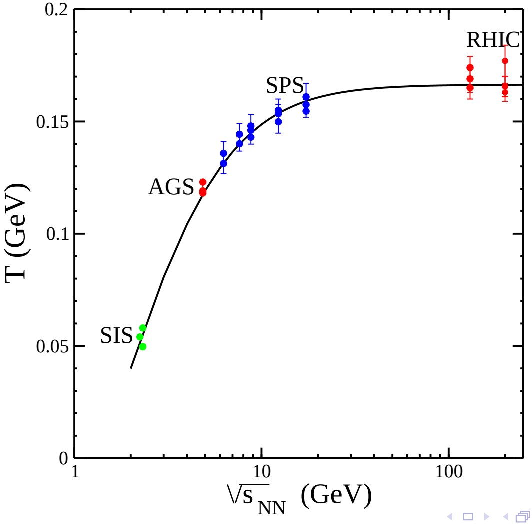


Chemical Freeze-Out

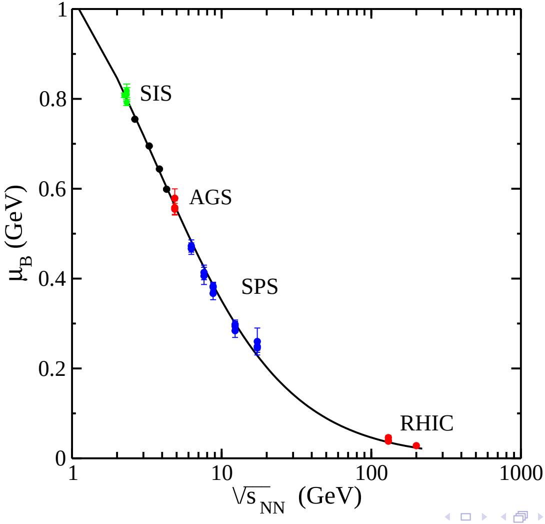


J.C., H. Oeschler, K. Redlich, S. Wheaton hep-ph/0511094

Chemical Freeze-Out Temperature



Chemical Freeze-Out μ_B

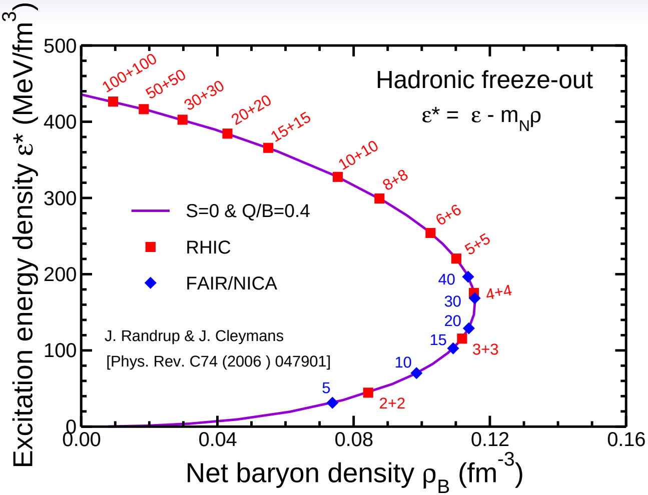


μ_B as a function of $\sqrt{s_{NN}}$

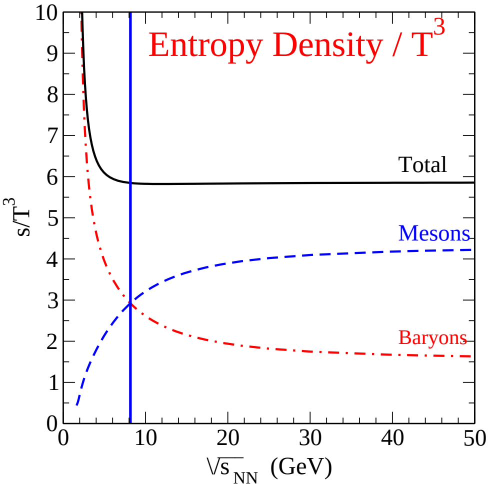
$$\mu_B(\sqrt{s}) = \frac{1.308\ \mathrm{GeV}}{1 + 0.273\ \mathrm{GeV}^{-1}\sqrt{s}}.$$

This predicts at LHC $\mu_B \approx 1$ MeV.

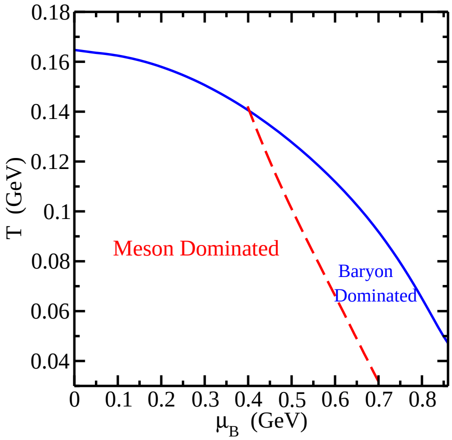
J. C., H. Oeschler, K. Redlich, S. Wheaton
Phys. Rev. C73 034905 (2006)


Hadronic freeze-out
ε* = ε - m_N ρ
S=0 & Q/B=0.4
RHIC
FAIR/NICA
J. Randrup & J. Cleymans
[Phys. Rev. C74 (2006) 047901]
100+100
50+50
30+30
20+20
15+15
10+10
8+8
6+6
5+5
4+4
3+3
2+2
40
30
20
15
10
5
Excitation energy density ε* (MeV/fm^3)
Net baryon density ρ_B (fm^-3)
0
100
200
300
400
500
0.00
0.04
0.08
0.12
0.16

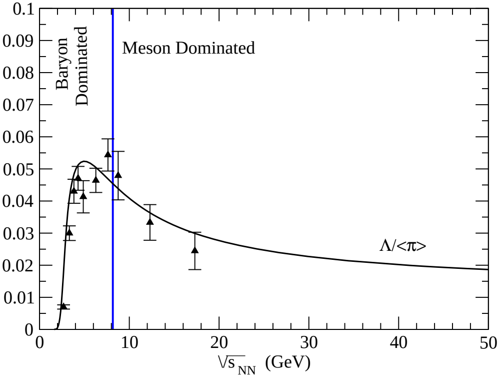
s/T^3


Entropy Density / T3
Total
Mesons
Baryons
s/T3
√sNN (GeV)
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50

Transition


0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
T (GeV)
Meson Dominated
Baryon
Dominated
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
μB (GeV)

Λ/π Ratio



Strangeness in Heavy Ion Collisions
vs
Strangeness in pp - collisions

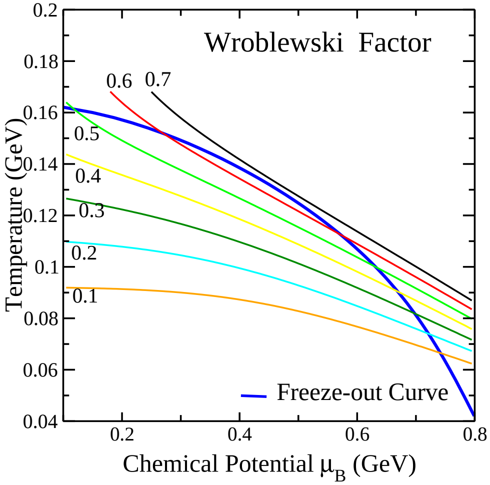
Use the Wroblewski factor

$$\lambda_s = \frac{2\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle}$$

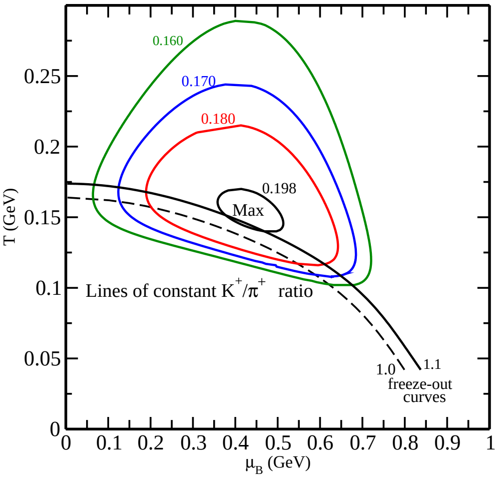
This is determined by the number of **newly** created quark – anti-quark pairs and **before** strong decays, i.e. before ρ's and Δ's decay.

Limiting values :
$\lambda_s = 1$ all quark pairs are equally abundant, SU(3) symmetry.
$\lambda_s = 0$ no strange quark pairs.

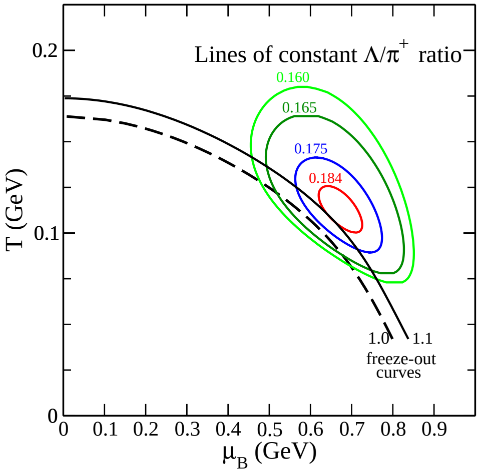
Maxima in particle ratios : K^+/π^+



Maxima in particle ratios : K^+/π^+



Maxima in particle ratios : K^+/π^+



J.C., H. Oeschler, K. Redlich, S. Wheaton, Phys. Lett. B615 (2005) 50-54

In the statistical model a rapid change is expected as the hadronic gas undergoes a transition from a baryon-dominated to a meson-dominated gas. The transition occurs at a temperature T = 140 MeV and baryon chemical potential μ_B = 410 MeV corresponding to an incident energy of $\sqrt{s_{NN}}$ = 8.2 GeV.

In conclusion, the roller-coaster seen in the particle ratios corresponds to a transition from a baryon-dominated to a meson-dominated hadronic gas. This transition occurs at a

- temperature $T = 140$ MeV,
- baryon chemical potential $\mu_B = 410$ MeV,
- energy $\sqrt{s_{NN}} = 8.2$ GeV.

In the statistical model this transition leads to a peaks in the $\Lambda/\langle\pi\rangle$, K^+/π^+, Ξ^-/π^+ and Ω^-/π^+ ratios.

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Thermal Model

The number of particles of type *i* is determined by:

$$E\frac{dN_i}{d^3p} = \frac{g_i}{(2\pi)^3}\int d\sigma_\mu p^\mu \exp\left(-\frac{p^\mu u_\mu}{T} + \frac{\mu_i}{T}\right)$$

Integrating this over all momenta

$$N_i = \frac{g_i}{(2\pi)^3}\int d\sigma_\mu \int \frac{d^3p}{E} p^\mu \exp\left(-\frac{p^\mu u_\mu}{T} + \frac{\mu_i}{T}\right)$$

or

$$N_i = \int d\sigma_\mu u^\mu n_i(T,\mu)$$

If the temperature and chemical potential are unique along the freeze-out curve

$$N_i = n_i(T,\mu)\int d\sigma_\mu u^\mu$$

i.e. integrated (4π) multiplicities are the same as for a single fireball at rest (apart from the volume).