Maximal Net Baryon Density in the Energy Region Covered by NICA.

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University of Cape Town, South Africa

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Stellenbosch Institute
for Advanced Studies
South Africa
April 6 – 9 2010

http://hep.phy.uct.ac.za/dm2010
http://th.physik.uni-frankfurt.de/~dm2010/home.shtml

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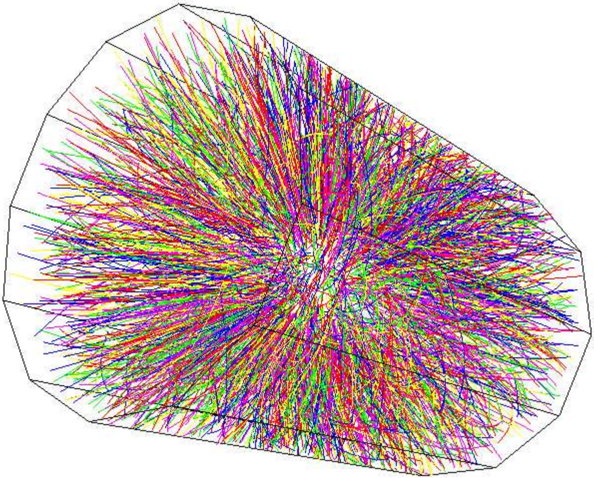


	Equilibrium
π	$\exp\left[-\frac{E_\pi}{T}\right]$
N	$\exp\left[-\frac{E_N}{T}+\frac{\mu_B}{T}\right]$
$\overline{N}$	$\exp\left[-\frac{E_N}{T}-\frac{\mu_B}{T}\right]$
Λ	$\exp\left[-\frac{E_\Lambda}{T}+\frac{\mu_B}{T}-\frac{\mu_S}{T}\right]$
$\overline{\Lambda}$	$\exp\left[-\frac{E_\Lambda}{T}-\frac{\mu_B}{T}+\frac{\mu_S}{T}\right]$
K	$\exp\left[-\frac{E_K}{T}+\frac{\mu_S}{T}\right]$
$\overline{K}$	$\exp\left[-\frac{E_K}{T}-\frac{\mu_S}{T}\right]$

SPS data.

	Measurement
Pb–Pb 158*A* GeV	
$(\pi^+ + \pi^-)/2.$	600±30
K^+	95 ±10
K^-	50 ±5
K^0_S	60 ±12
p	140±12
$\bar{p}$	10 ±1.7
ϕ	7.6±1.1
Ξ^-	4.42±0.31
$\overline{\Xi^-}$	0.74±0.04
$\overline{\Lambda}/\Lambda$	0.2±0.04

SPS data.

SPS: Freeze-Out Parameters:

$$\begin{aligned} T &= 156.0 \pm 2.4\mathrm{MeV} \\ \mu_B &= 239 \pm 12\mathrm{MeV} \end{aligned}$$

F. Becattini, J.C., A. Keränen, E. Suhonen and K. Redlich
Physical Review C64 (2001) 024901.

AGS data.

	Measurement
Au–Au 11.6*A* GeV	
Participants	363±10
K^+	23.7±2.9
K^-	3.76±0.47
π^+	133.7±9.9
Λ	20.34±2.74
p/π^+	1.234±0.126
$\bar{p}$	$>$0.0185±0.0018

AGS data.

AGS: Freeze-Out Parameters:

$$\begin{aligned} T &= 130.6 \pm 5.5\mathrm{MeV} \\ \mu_B &= 594 \pm 26\mathrm{MeV} \end{aligned}$$

F. Becattini, J.C., A. Keränen, E. Suhonen and K. Redlich
Physical Review C64 (2001) 024901.

SIS data.

	Measurement
Au–Au 1.7*A* GeV	
π^+/p	0.052±0.013
K$^+/\pi^+$	0.003±0.00075
π^-/π^+	2.05±0.51
η/π^0	0.018±0.007

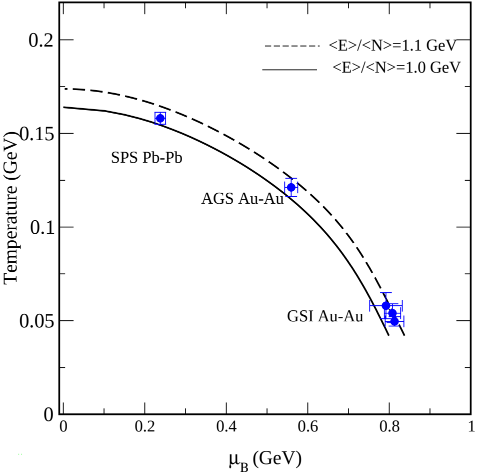
SIS data.

SIS: Freeze-Out Parameters:

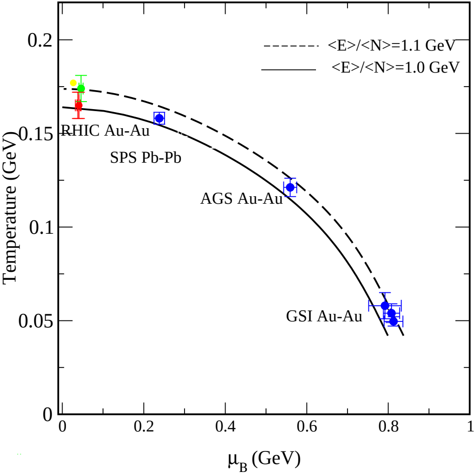
$$\begin{aligned} T &= 49.7 \pm 1.1\mathrm{MeV} \\ \mu_B &= 818 \pm 15\mathrm{MeV} \end{aligned}$$

J. C., H. Oeschler and K. Redlich)
Physical Review C59, (1999) 1663.

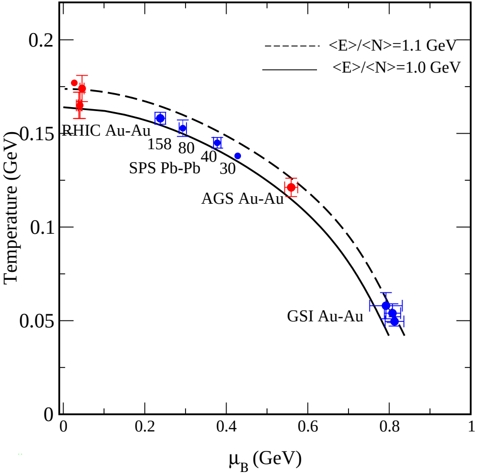
E/N in 1999


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

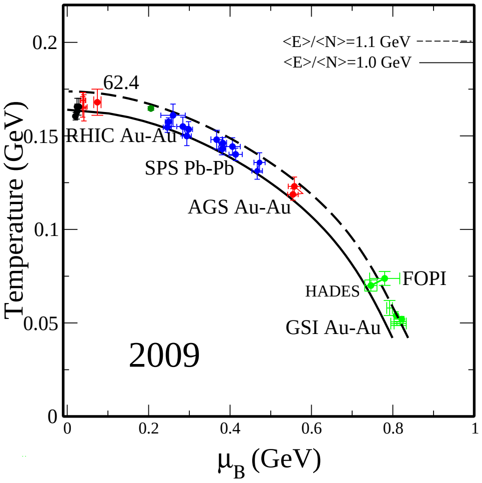
E/N in 2000


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

E/N in 2005

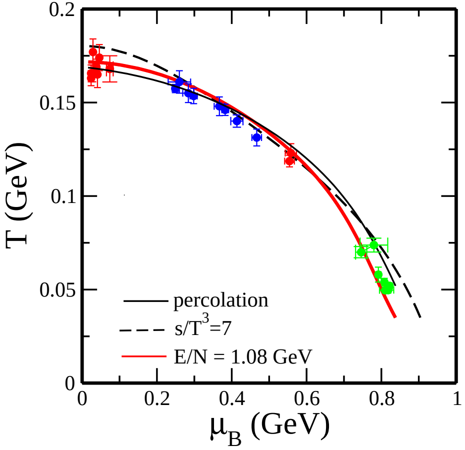

<E>/<N>=1.1 GeV
<E>/<N>=1.0 GeV
RHIC Au-Au
158
80
40
30
SPS Pb-Pb
AGS Au-Au
GSI Au-Au
Temperature (GeV)
0
0.05
0.1
0.15
0.2
μ_B (GeV)
0
0.2
0.4
0.6
0.8
1

E/N in 2009

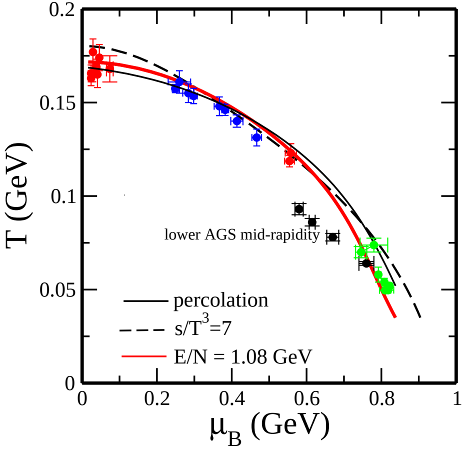


A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772, 167, 2006
J. Manninen, F. Becattini, M, Gazdzicki, Phys. Rev. C73 044905, 2006
R. Picha, U of Davis, Ph.D. thesis 2002
J. Takahashi, SQM2008

Chemical Freeze-Out: Criteria



Chemical Freeze-Out: Criteria



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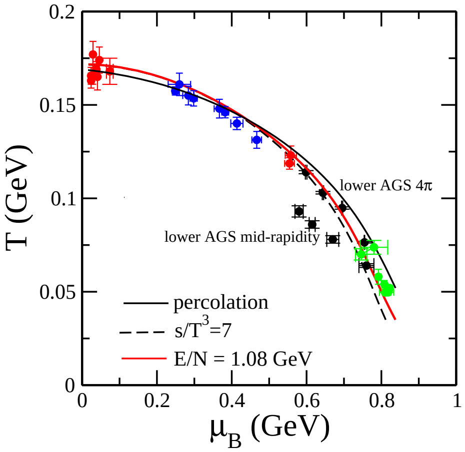
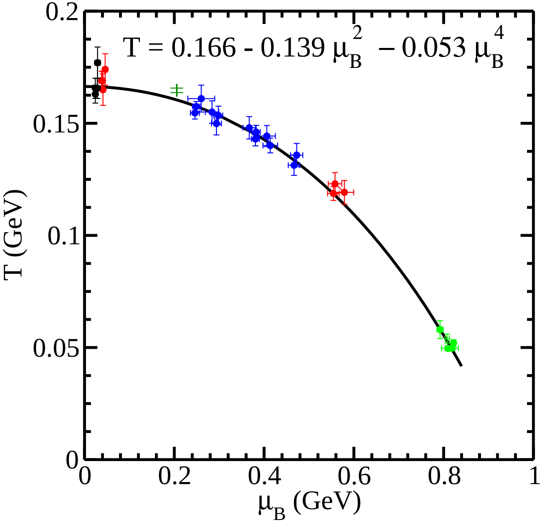
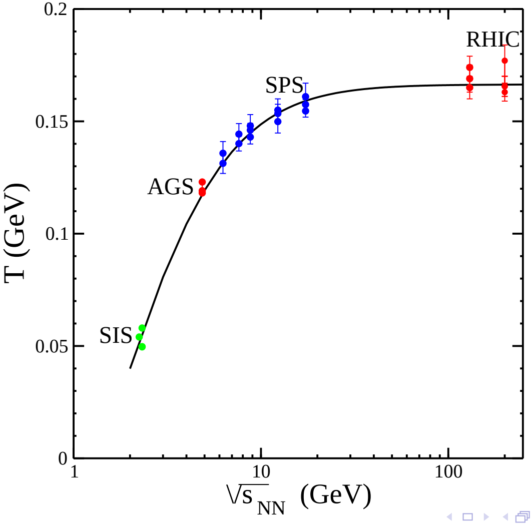


Chemical Freeze-Out

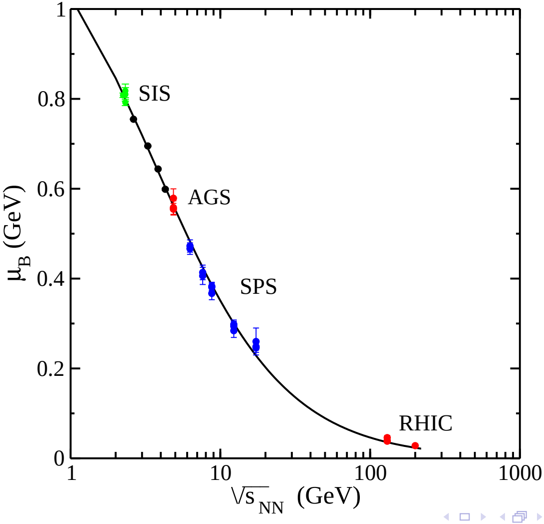


J.C., H. Oeschler, K. Redlich, S. Wheaton hep-ph/0511094

Chemical Freeze-Out Temperature



Chemical Freeze-Out μ_B

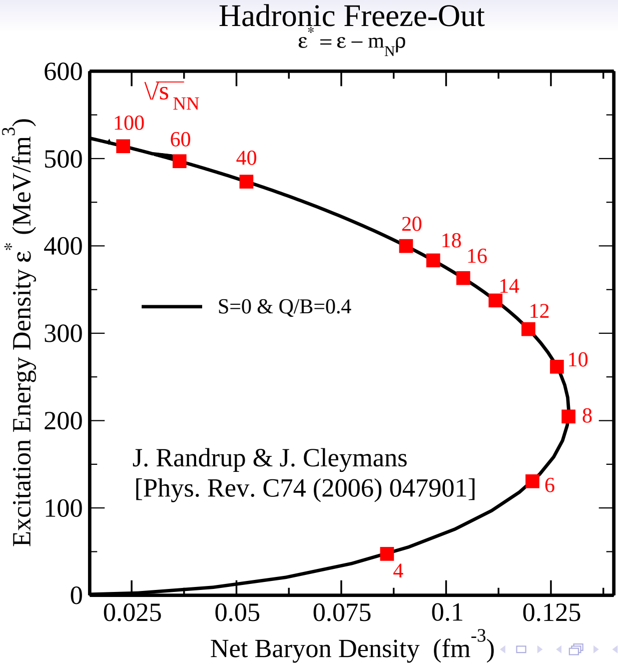


μ_B as a function of $\sqrt{s_{NN}}$

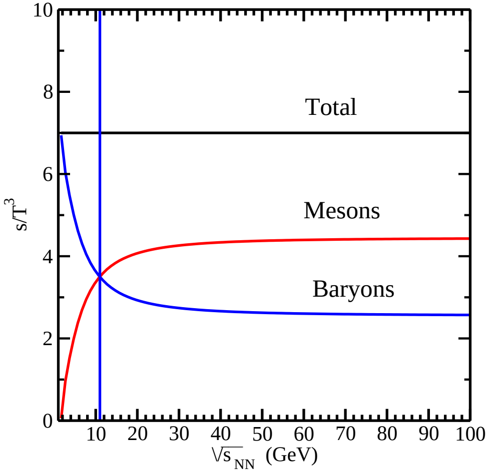
$$\mu_B(\sqrt{s}) = \frac{1.308\ \mathrm{GeV}}{1 + 0.273\ \mathrm{GeV}^{-1}\sqrt{s}}.$$

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

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

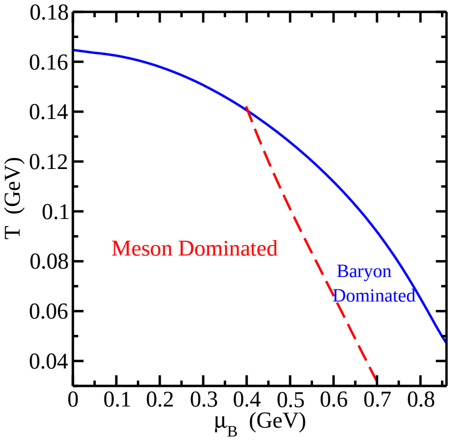

Hadronic Freeze-Out
$\varepsilon^* = \varepsilon - m_N\rho$
$\sqrt{s}_{NN}$
100
60
40
20
18
16
14
12
10
8
6
4
S=0 & Q/B=0.4
J. Randrup & J. Cleymans
[Phys. Rev. C74 (2006) 047901]
Excitation Energy Density ε^* (MeV/fm^3)
Net Baryon Density (fm^{-3})
0
100
200
300
400
500
600
0.025
0.05
0.075
0.1
0.125

s/T^3

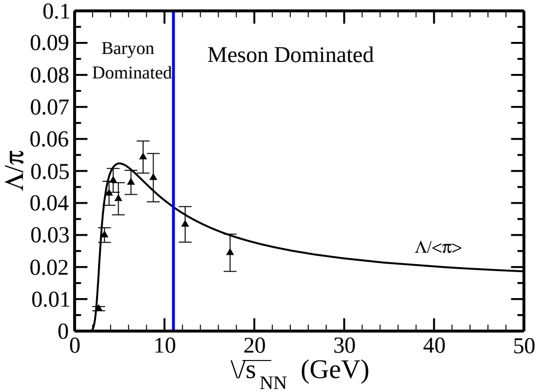


J. C., H. Oeschler, K. Redlich and S. Wheaton, Physics Letters B615 (2005) 50-54.

Transition


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

Λ/π Ratio



THERMUS

S. Wheaton, J. Cleymans, M. Hauer

Comp. Phys. Comm. 180 (2009) 84-106

Strangeness in Heavy Ion Collisions
vs
Strangeness in pp - collisions

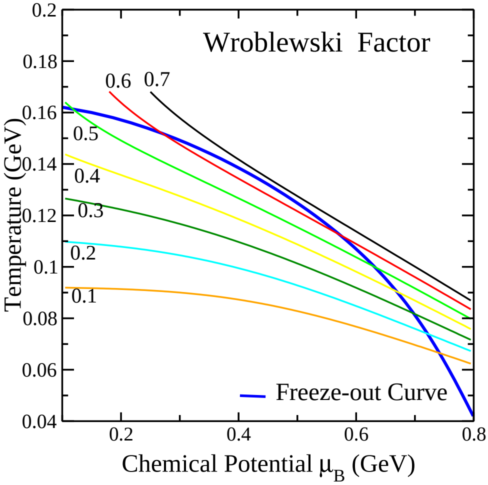
Use the Wroblewski factor

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

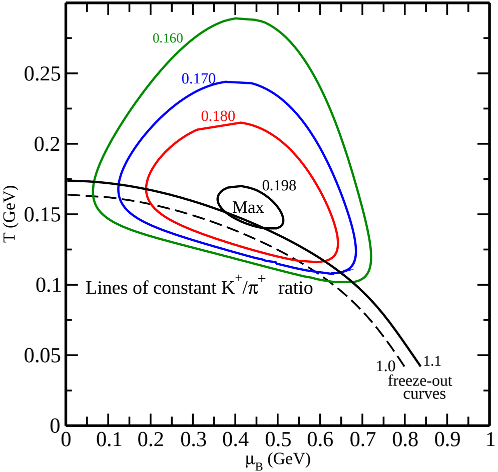
This is determined by the number of **newly** created quark – anti-quark pairs and **before** strong decays, i.e. before ρ's and Δ's decay.

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

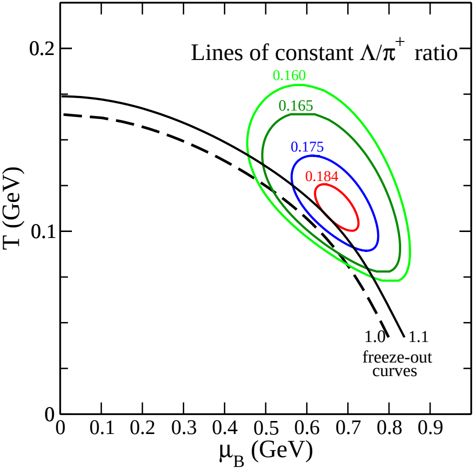
Maxima in particle ratios : K^+/π^+

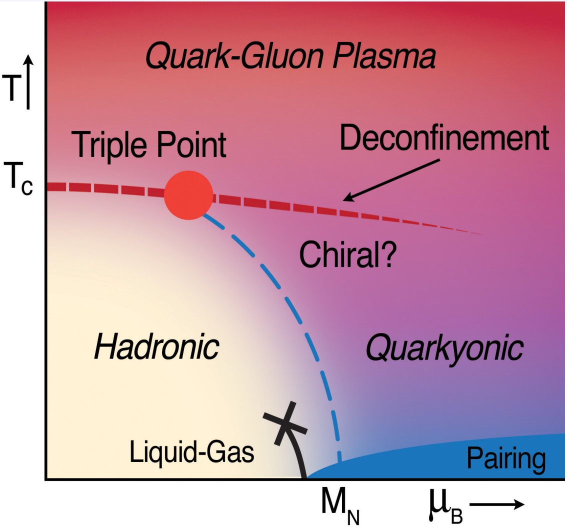


Maxima in particle ratios : K^+/π^+



Maxima in particle ratios : K^+/π^+





R. Pisarski and L. McLerran

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 = 151 MeV and baryon chemical potential μ_B = 327 MeV corresponding to an incident energy of $\sqrt{s_{NN}}$ = 11 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 $T = 151$ MeV,
- baryon chemical potential $\mu_B = 327$ MeV,
- energy $\sqrt{s_{NN}} = 11$ GeV.

In the statistical model this transition leads to 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).