Thermal model predictions of hadron ratios

A Andronic[1], **P Braun-Munzinger**[1,2], **J Stachel**[3]

[1] Gesellschaft für Schwerionenforschung, GSI, D-64291 Darmstadt, Germany

[2] Technical University Darmstadt, D-64283 Darmstadt, Germany

[3] Physikalisches Institut der Universität Heidelberg, D-69120 Heidelberg, Germany

Abstract. We present predictions of the thermal model for hadron ratios in central Pb+Pb collisions at LHC.

Hadron yields signal chemical equilibrium

- From AGS energy on, all hadron yields in central PbPb collisions reflect grand-canonical equilibration
- Strangeness suppression observed in elementary collisions is lifted

For a recent review see:

pbm, Stachel, Redlich, QGP3, R. Hwa, editor, Singapore 2004, nucl-th/0304013

Thermal model description of hadron yields

Grand Canonical Ensemble

$$\ln Z_i = \frac{V g_i}{2\pi^2} \int_0^\infty \pm p^2 dp \ln(1 \pm \exp(-(E_i - \mu_i)/T))$$

$$n_i = N/V = -\frac{T}{V}\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2} \int_0^\infty \frac{p^2\, dp}{\exp((E_i - \mu_i)/T) \pm 1}$$

$$\mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_i^3$$

for every conserved quantum number there is a chemical potential μ
but can use conservation laws to constrain:

- Baryon number: $V \sum_i n_i B_i = Z + N \quad \to V$
- Strangeness: $V \sum_i n_i S_i = 0 \quad \to \mu_S$
- Charge: $V \sum_i n_i I_i^3 = \frac{Z - N}{2} \quad \to \mu_{I_3}$

This leaves only μ_b and T as free parameter when 4π considered

for rapidity slice fix volume e.g. by dN_{ch}/dy

Fit at each energy provides values for T and μ_b

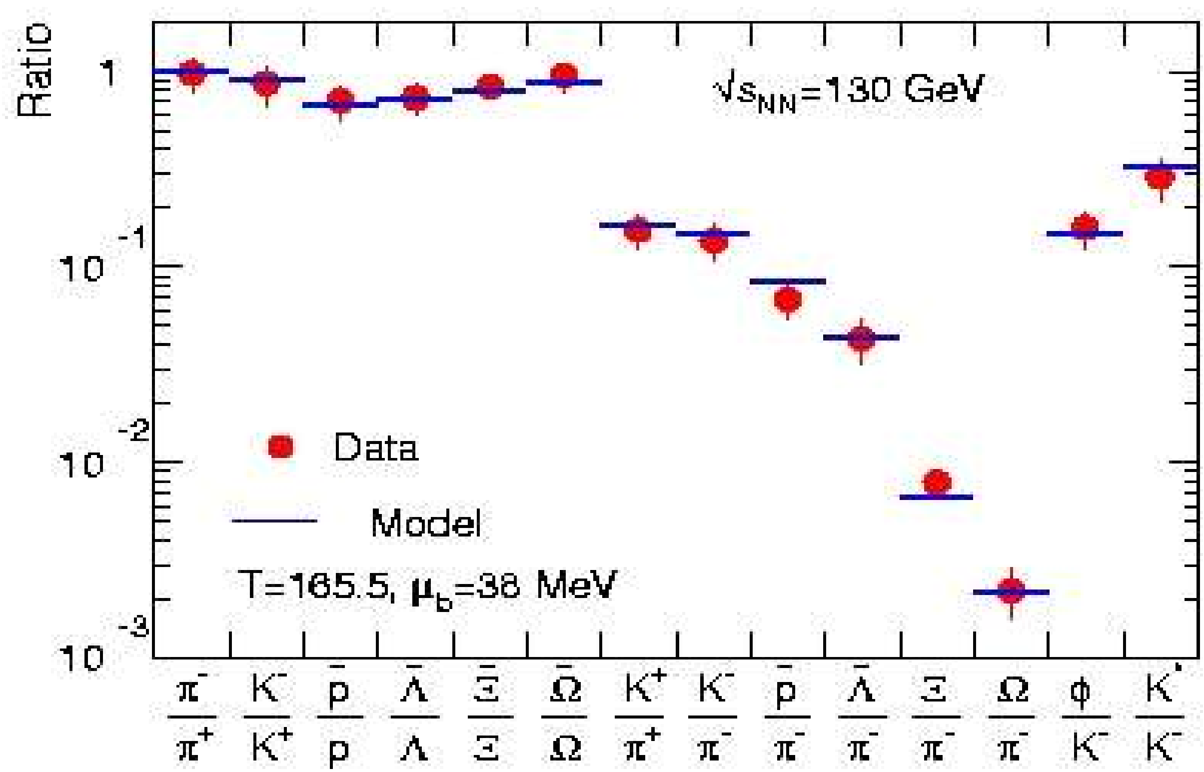
Hadro-chemistry at RHIC -- weakly decaying particles

All data in excellent agreement with thermal model predictions

chemical freeze-out at: T = 165 ± 8 MeV

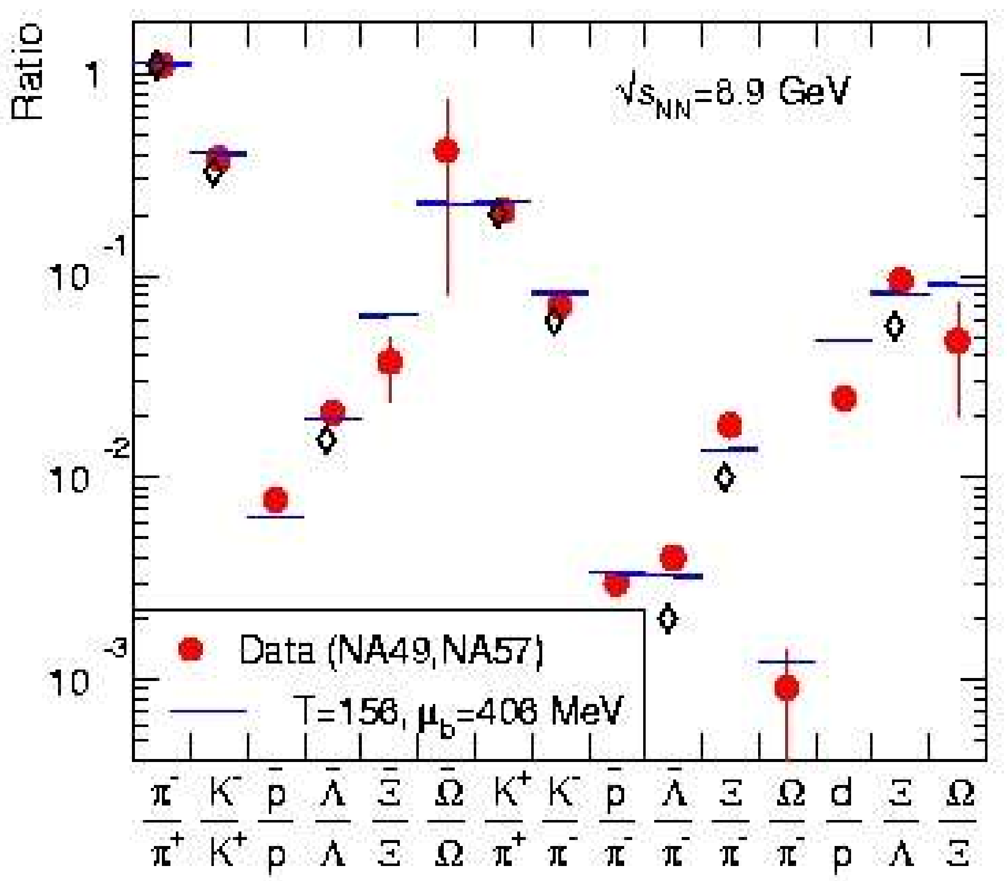
fit uses vacuum masses

most recent analysis: A. Andronic, pbm, J. Stachel, nucl-th/0511071 Nucl. Phys. A772 (2006) 167



pbm, d. magestro, j. stachel, k. redlich, Phys. Lett. B518 (2001) 41; see also Xu et al., Nucl. Phys. A698(2002) 306; Becattini, J. Phys. G28 (2002) 1553; Broniowski et al., nucl-th/0212052.

Hadro-chemistry at SPS



Data at 40 GeV/u Pb+Pb central collisions

T = 156 MeV,

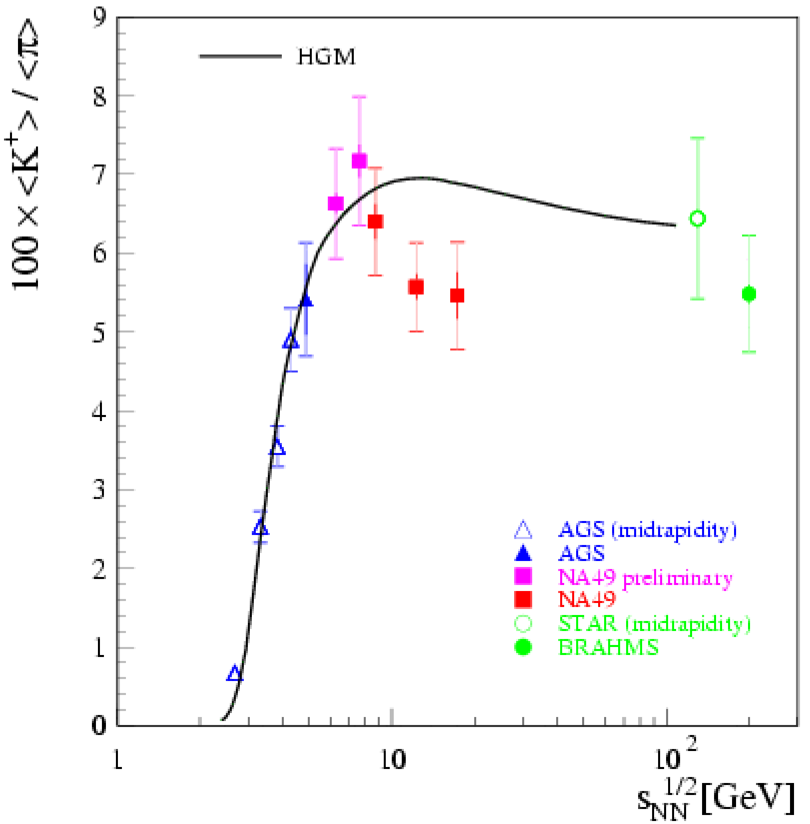
μ_b= 406 MeV

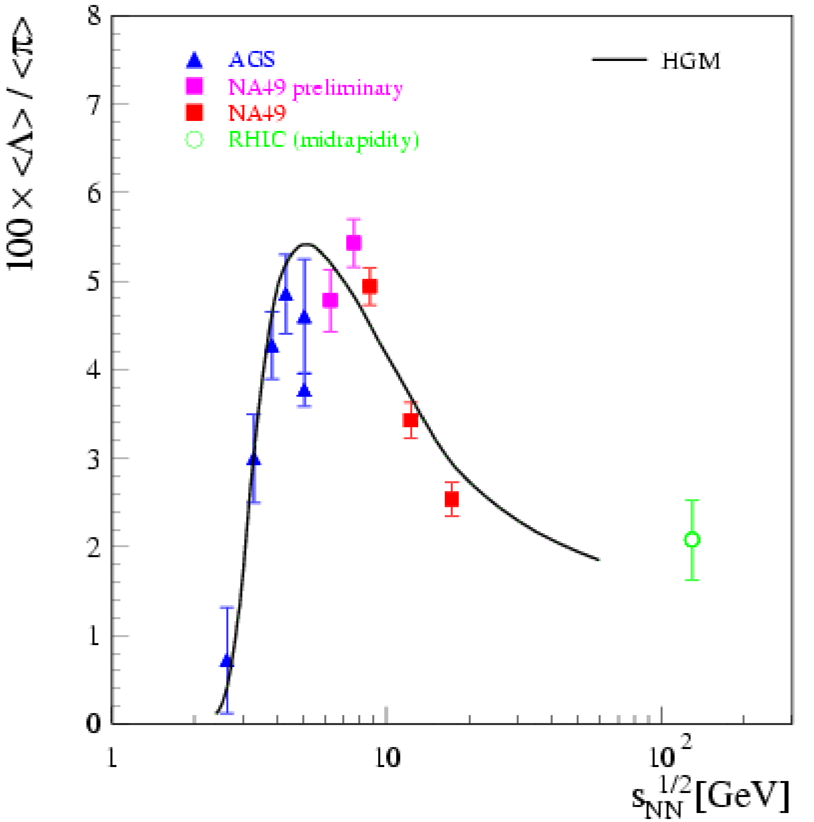
analysis from Andronic, pbm, Stachel,

nucl-th/0511071

Nucl. Phys. A772 (2006) 167

Open Issue: the NA49 „horn“ in K/π

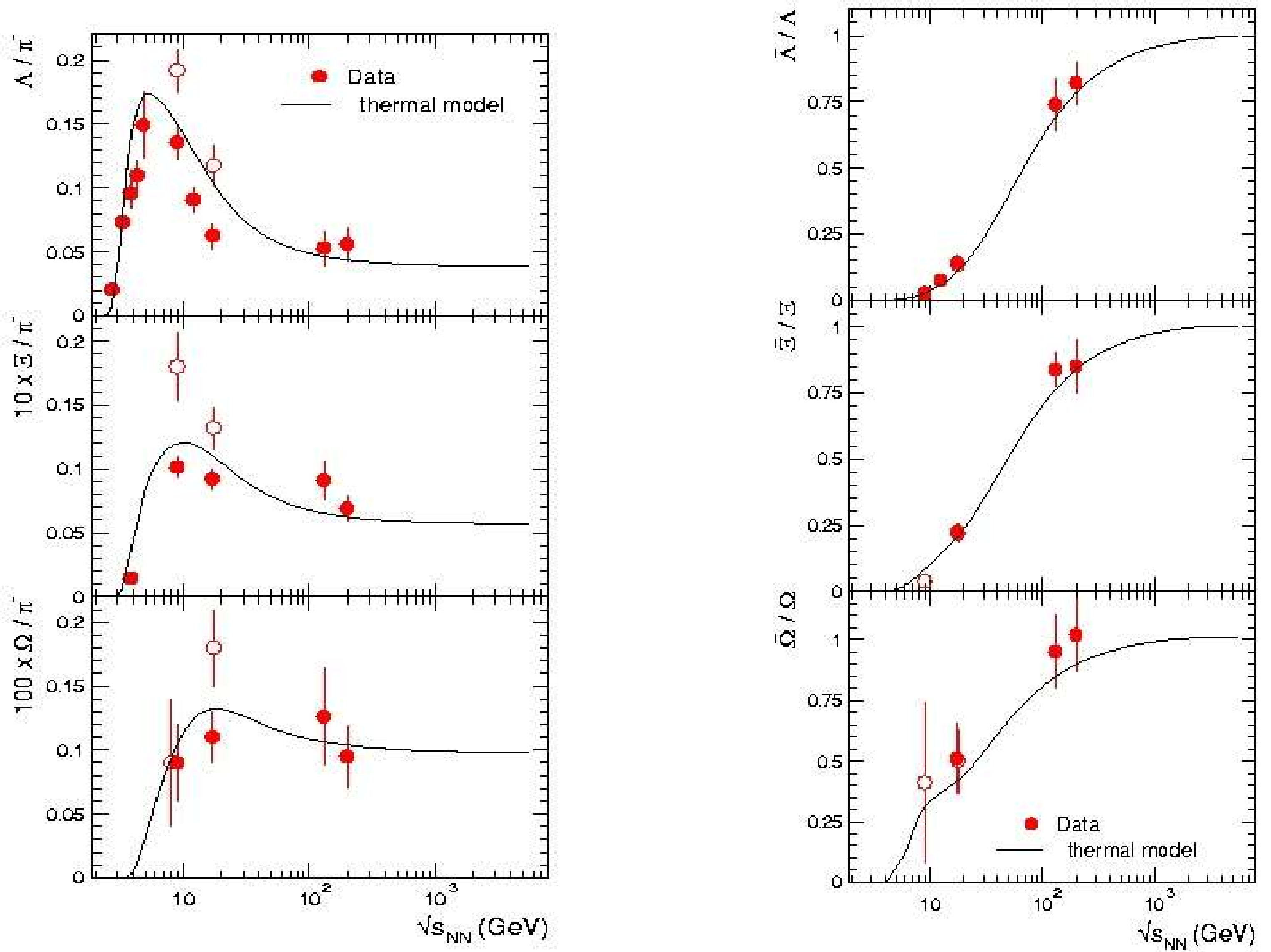




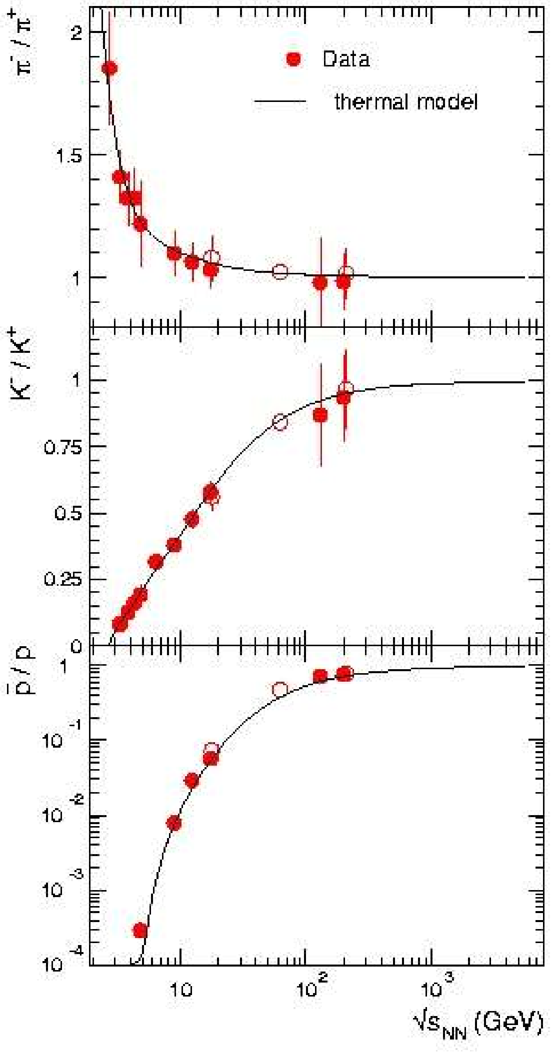
The structure near √s = 8 GeV is not reproduced but note: natural „ smearing“ is ≈ 3 GeV near √s = 8 GeV

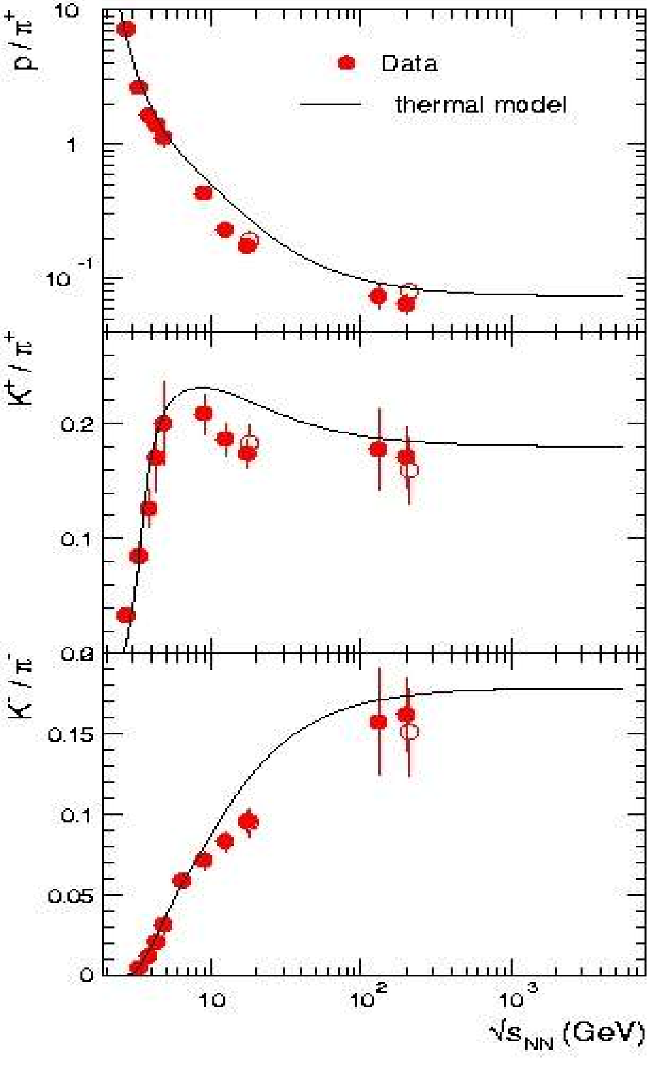
Strangeness undersaturated at 80 and 160 A GeV, saturated at all other energies?

excitation functions and thermal model predictions



excitation functions and thermal model predictions





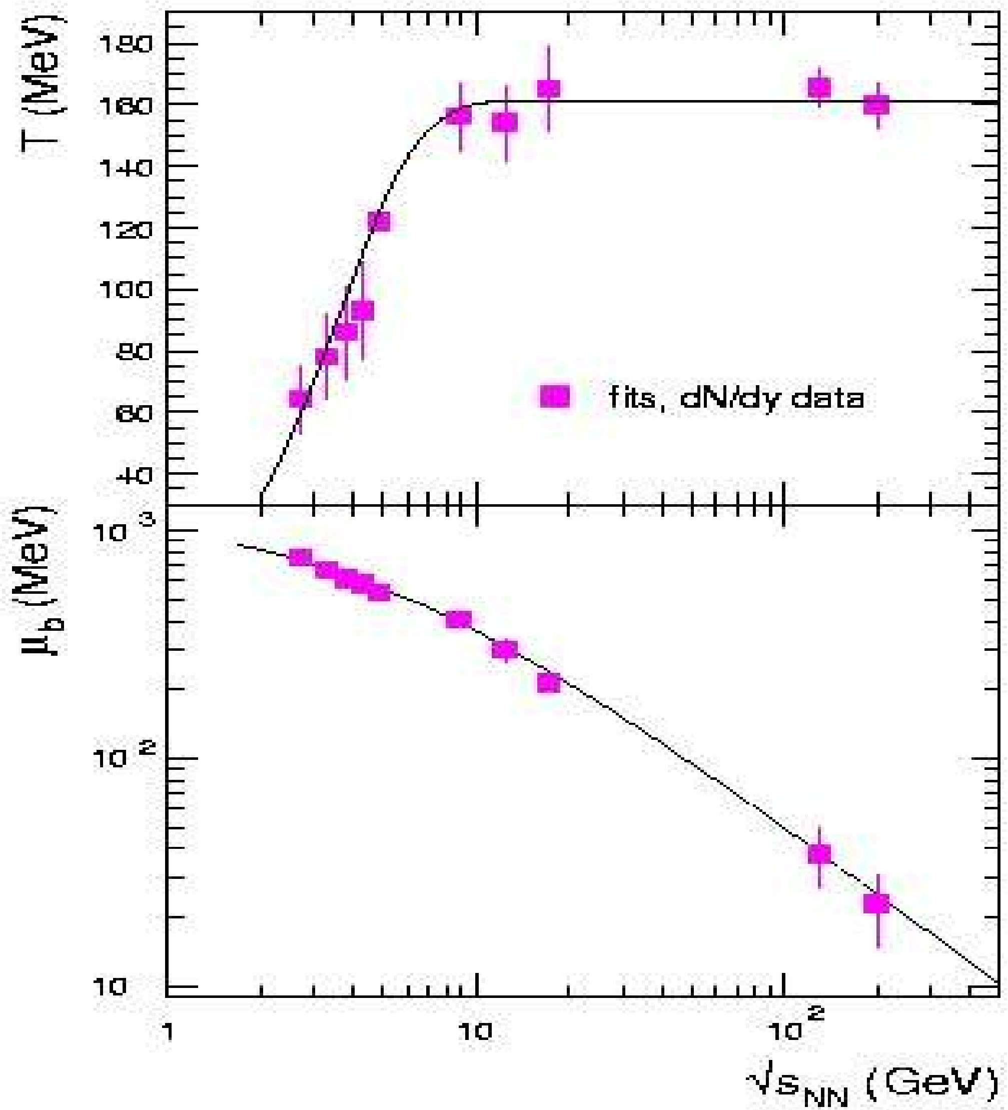
The limiting temperature is T_c

T_{lim} = 160 MeV

T_c = 160 (+12 -16) MeV

estimated systematic errors

A. Andronic, pbm, J. Stachel,
Nucl. Phys. A772 (2006) 167
nucl-th/0511071



Chemical freeze-out determines T_c for small

phase transition brings multi-strange (and all other hadrons) into equilibrium

chemical freeze-out temperature closely coincides with critical temperature

determination of a fundamental QCD parameter from experiments on hadron production in ultra-relativistic nuclear collisions

T_c = 160 (+12 -16) MeV

2 sigma discrepancy with latest lattice resuts of Bielefeld/Columbia/BNL group, but in agreement with Fodor et al., see also T. Hatsuda, hep-ph/0702293

first prediction of particle ratios at LHC energy

pbm, Nucl. Phys. A661 (1999) 261

invited paper, QM1999 conference, Torino, Italy

results to within 10 % in agreement with current predictions

baryon chemical potential still unknown (10 MeV used) from SPS and RHIC systematics, the thermal model parameters at LHC energy are estimated to be:

$$T{=}161{\pm}4 \text{ MeV and } \mu_b{=}0.8^{+1.2}_{-0.6} \text{ MeV}$$

all predictions are made for yields at mid-rapidity
in central Pb-Pb collisions

Table 1. Predictions of the thermal model for hadron ratios in central Pb+Pb collisions at LHC. The numbers in parantheses represent the error in the last digit(s) of the calculated ratios.

π^-/π^+	K^-/K^+	$\bar{p}/p$	$\bar{\Lambda}/\Lambda$	$\bar{\Xi}/\Xi$	$\bar{\Omega}/\Omega$
1.001(0)	0.993(4)	$0.948^{-0.013}_{+0.008}$	$0.997^{-0.011}_{+0.004}$	$1.005^{-0.007}_{+0.001}$	1.013(4)

p/π^+	K^+/π^+	K^-/π^-	Λ/π^-	Ξ^-/π^-	Ω^-/π^-
0.074(6)	0.180(0)	0.179(1)	0.040(4)	0.0058(6)	0.00101(15)

Table 2. Predictions for the relative abundance of resonaces at chemical freeze-out.

ϕ/K^-	K^{*0}/K^0_S	Δ^{++}/p	$\Sigma(1385)^+/\Lambda$	Λ^*/Λ	$\Xi(1530)^0/\Xi^-$
0.137(5)	0.318(9)	0.216(2)	0.140(2)	0.075(3)	0.396(7)

predictions for other particle ratios are available upon request from the authors