Quark Matter 2018 Venezia

The QCD Phase Diagram from Statistical Model Analysis

Reinhard Stock

together with F. Becattini, J. Steinheimer and M. Bleicher

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

FIAS Frankfurt Institute for Advanced Studies

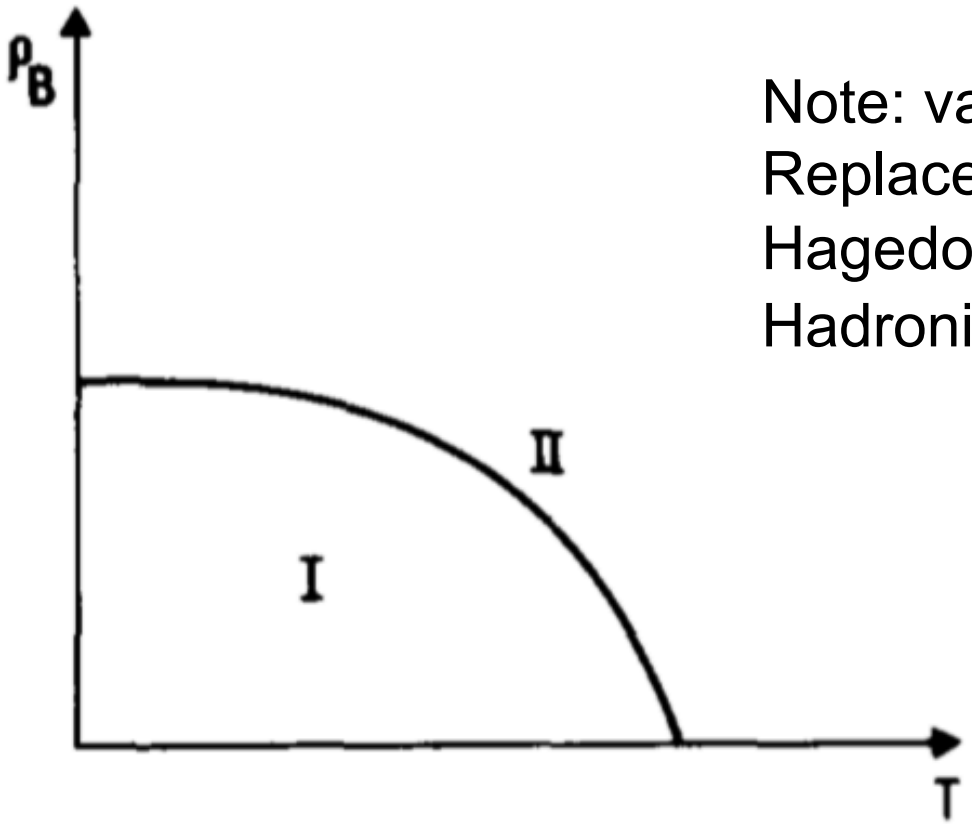
Hagedorns limiting hadronic temperature T_H

Interpreted by Cabibbo and Parisi 1975 as indication of a second order phase transition to QGP
Phys.Lett. B59 (1975) 67

The currently accepted interpretation of the properties of hadronic matter is based on the "realistic" quark model where quarks are permanently confined in hadrons. We expect models of this kind to give rise to a phase transition at a temperature $kT \approx m_\pi$, the high temperature phase being one where quarks can move freely in space.

-> Deconfinement at T_H to a new QCD phase

The first QCD Phase Diagram



Note: variables here are (T, ρ_B). Replaced later by (T, μ_B) in the Hagedorn-inspired Statistical Hadronization Model

Fig. 1. Schematic phase diagram of hadronic matter. ρ_B is the density of baryonic number. Quarks are confined in phase I and unconfined in phase II.

First view of deconfinement in relativistic A+A collisions

- about 1980 T.D.Lee: „Distributing enough energy density in space to melt the physical vacuum“

- „Physical Vacuum“ ≡ Color fields confined in hadrons

- after „melting“ ≡ Color fields permeate all space: QCD Plasma

Hadronization occurs at the QCD Phase Boundary

Note: With $T_H \approx 160$ MeV we are in non-perturbative QCD

→ Phenomenological models and Lattice QCD

Amati, Veneziano, Webber
Phys.Lett B83 (1979) 87

See below

$e^+ + e^- \rightarrow$ hadrons

The Veneziano-Webber Model

e^+e^- Annihilation to Hadrons: QCD DGLAP

Note: the photon is "virtual":
It has E_{CM} but no P_{CM}!
For "real" particles: $E^2 = p^2 + m^2$

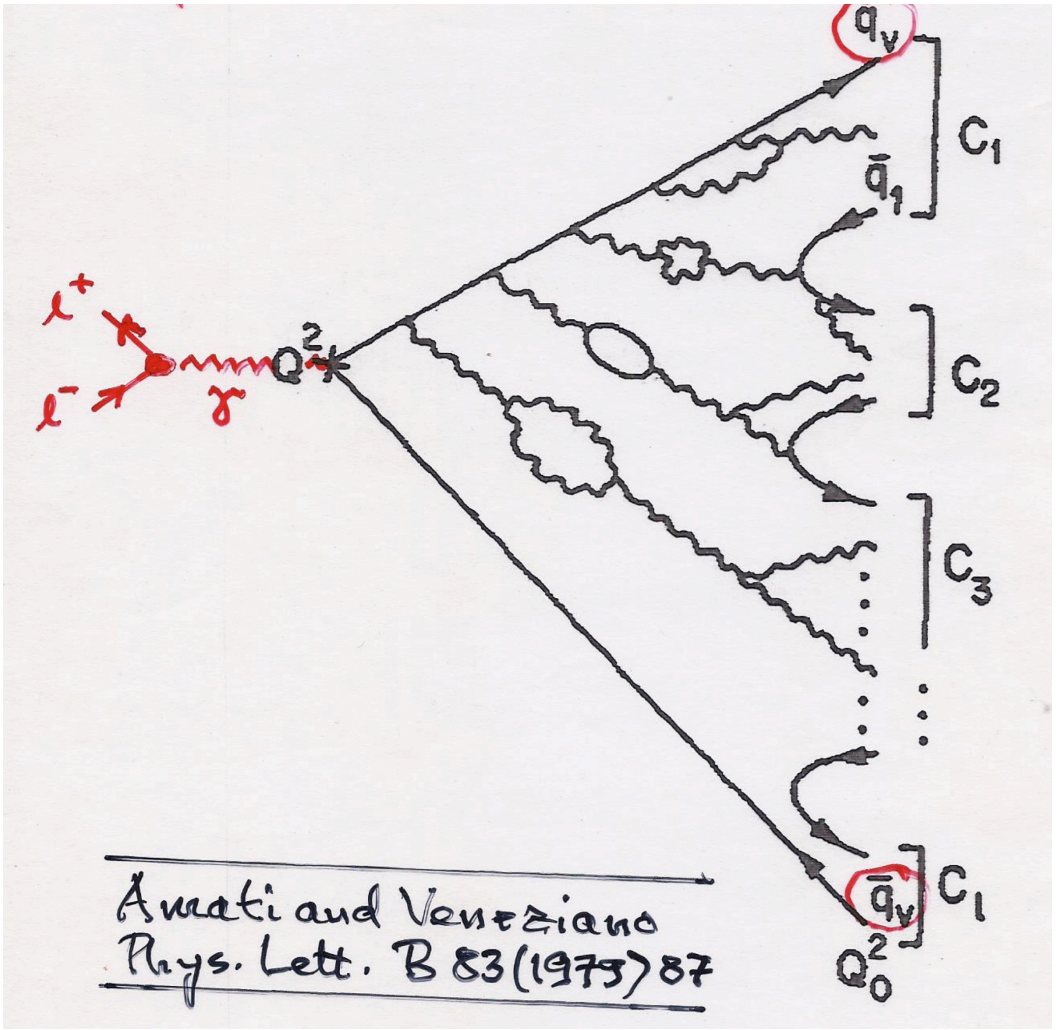
Virtuality ≈ virtual mass!

End of pQCD phase: spatial order of color in "cluster" regions:

"Color pre-confinement!"

Quantum Mechanical cluster decay:

Fermis Golden Rule,
Phase space weights
dominate hadron yields



PHYSICAL REVIEW D VOLUME 54, NUMBER 3 1 AUGUST 1996

Space, time, and color in hadron production via $e^+e^- \to Z^0$ and $e^+e^- \to W^+W^-$

John Ellis* and Klaus Geiger†
CERN TH-Division, CH-1211 Geneva 23, Switzerland
(Received 14 November 1995)

Second, it is evident that at a macroscopic level the overall space-time evolution is only marginally different for scenarios 1–3, implying that the gross features of the dynamical parton-hadron conversion are primarily determined by kinematics and the way in which the particles occupy phase space, and to a much lesser extent by the role of the internal color degrees of freedom.

The Hagedorn Legacy: Statistical Hadronization Model

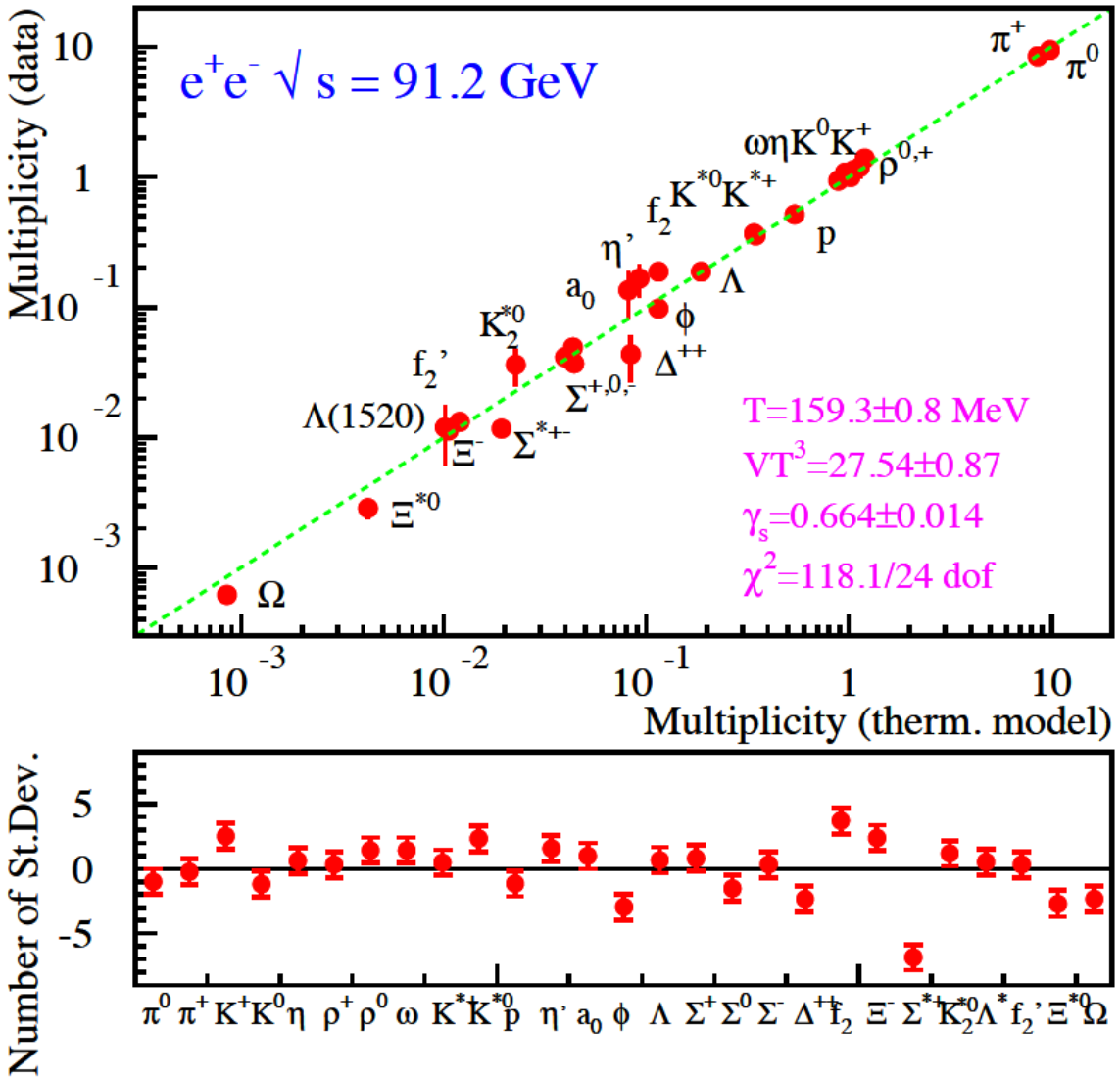
Francesco Becattini
Nucl.Phys. A702 (2002) 336

LEP data

Canonical statistical model analysis

T≈160 MeV the hadronization temperature

Phase space weights plus quantum number conservation



Grand Canonical Model in A+A Collisions

A complication in A+A:

- Final State Interaction in the final hadronic cascade expansion changes the yield distribution of hadronic species

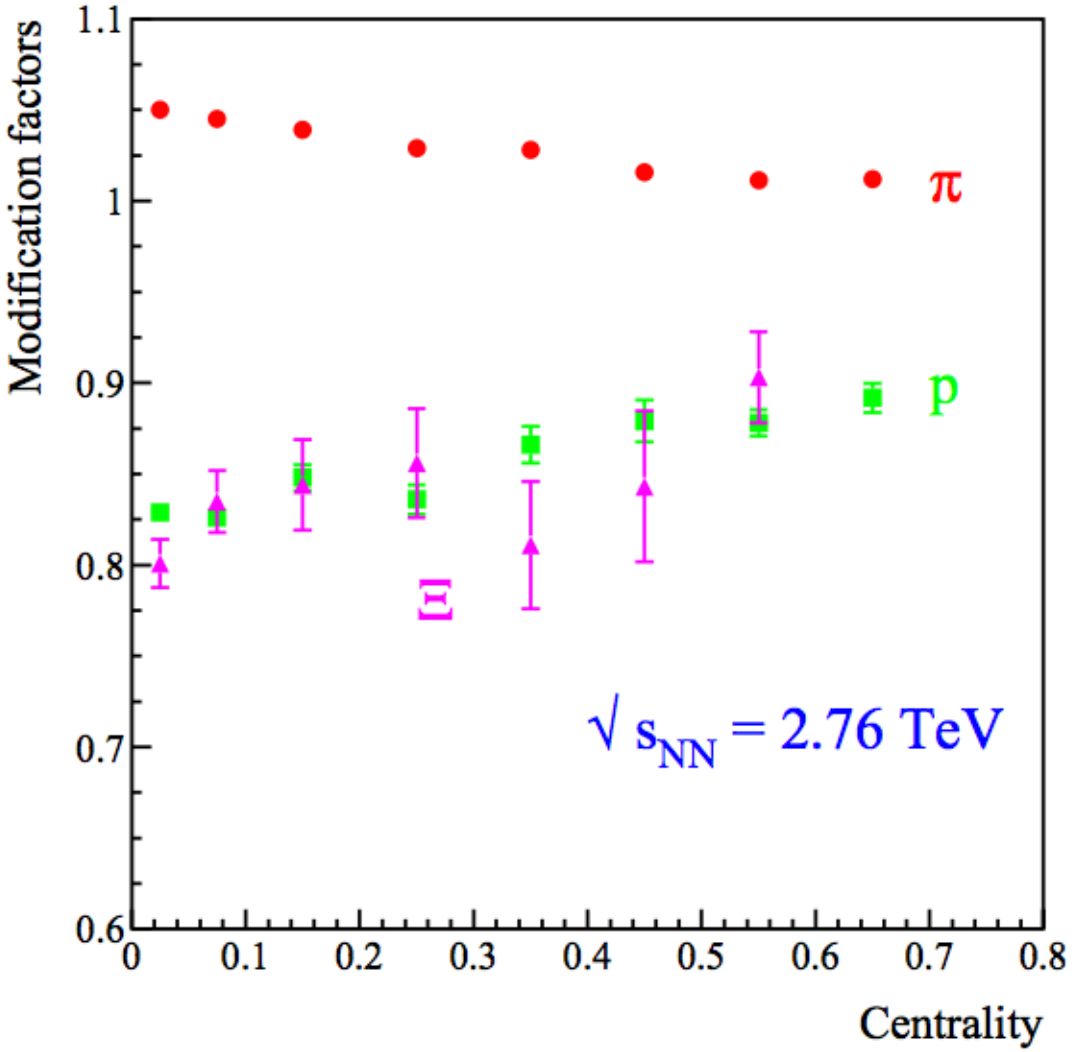
- Annihilation of Baryons (Anti-Baryons)

(F.Becattini et al., arXiv:1212.2431,
Phys.Rev.Lett. 111 (2013) 082302)

UrQMD in Pb+Pb at 2.76 TeV
Modification factors

F.Becattini et al.,
arXiv:1405.0710

Annilation effects
increase towards b=0

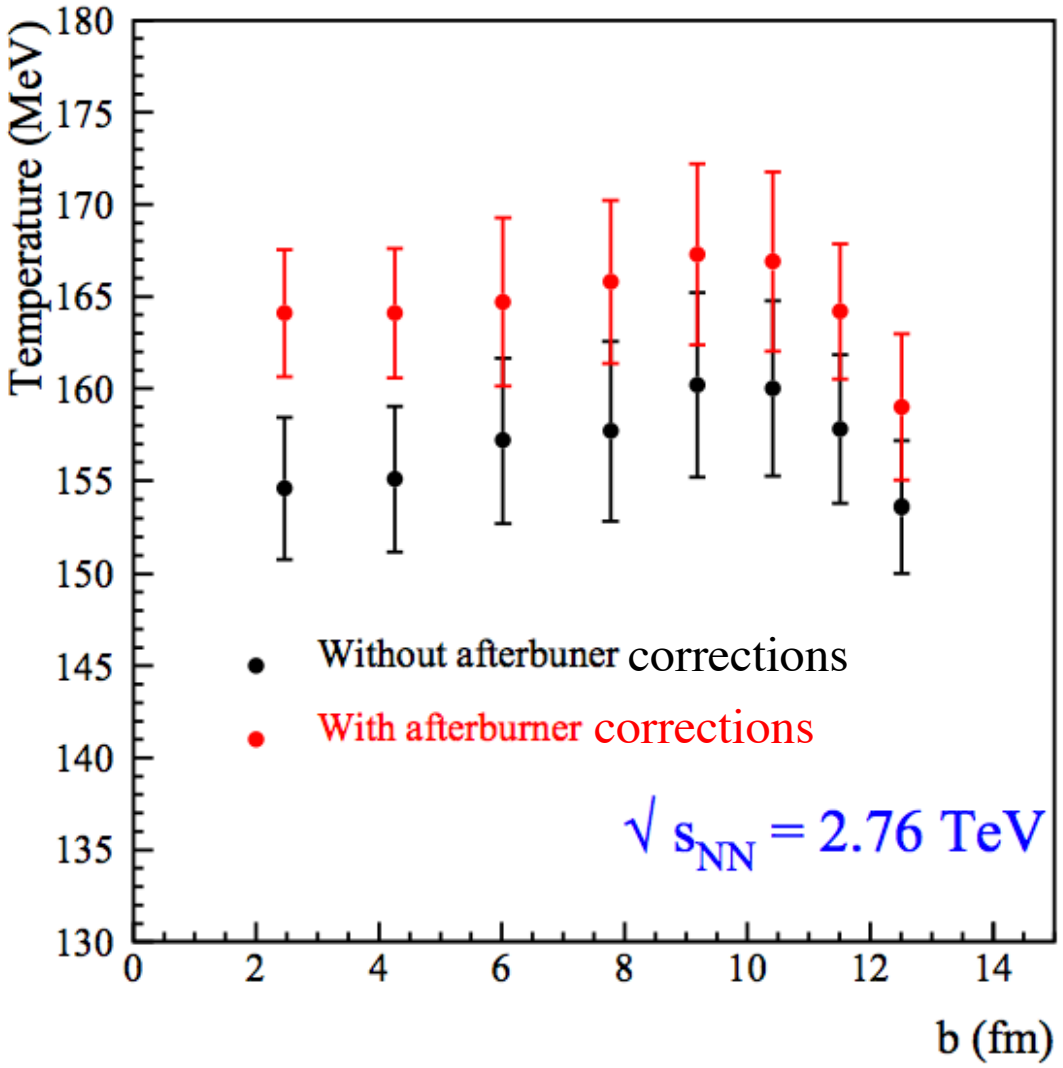


Apply Modification Factors in the Statistical Model

F.Becattini et al., arXiv:1405.0710

Pb+Pb minimum bias (ALICE)

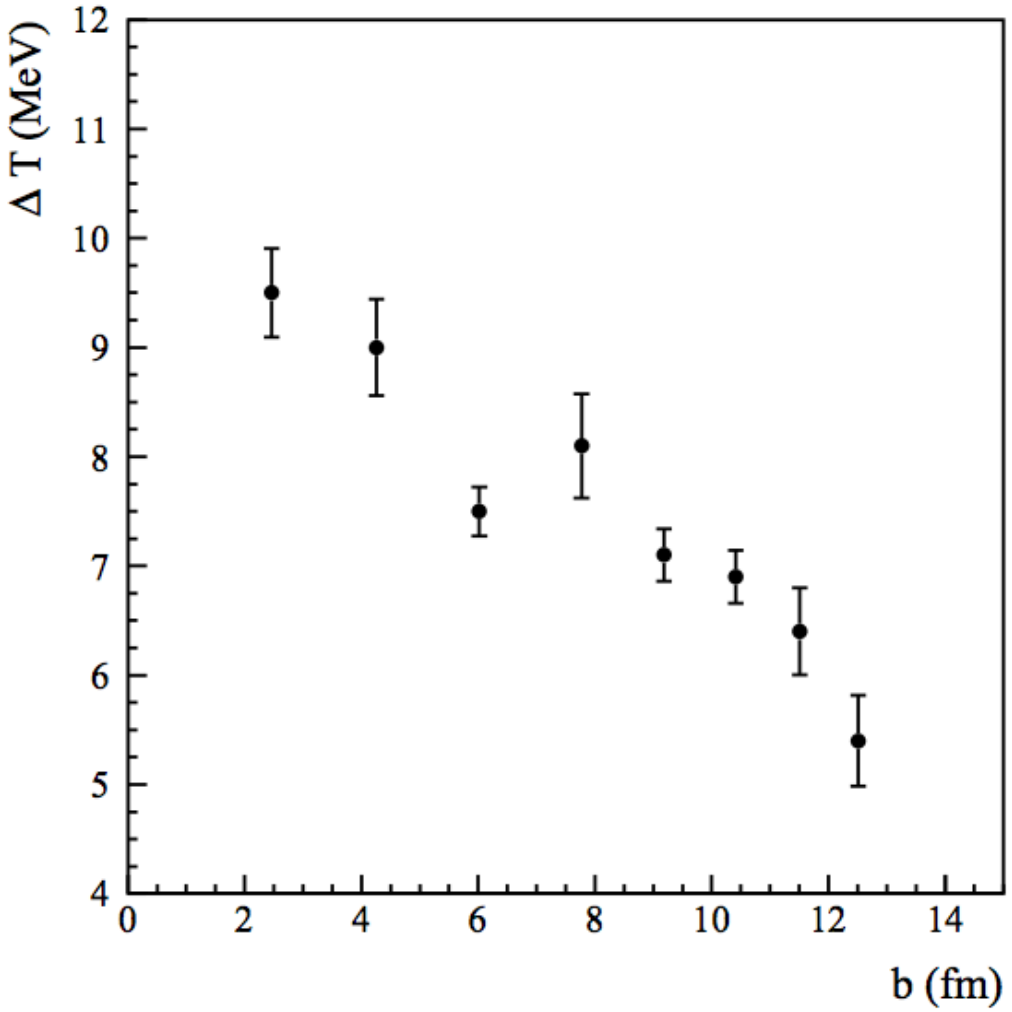
T_c = 164 ± 4 MeV in central Pb+Pb collisions



Modifications versus Centrality

F.Becattini et al.,
arXiv:1405.0710

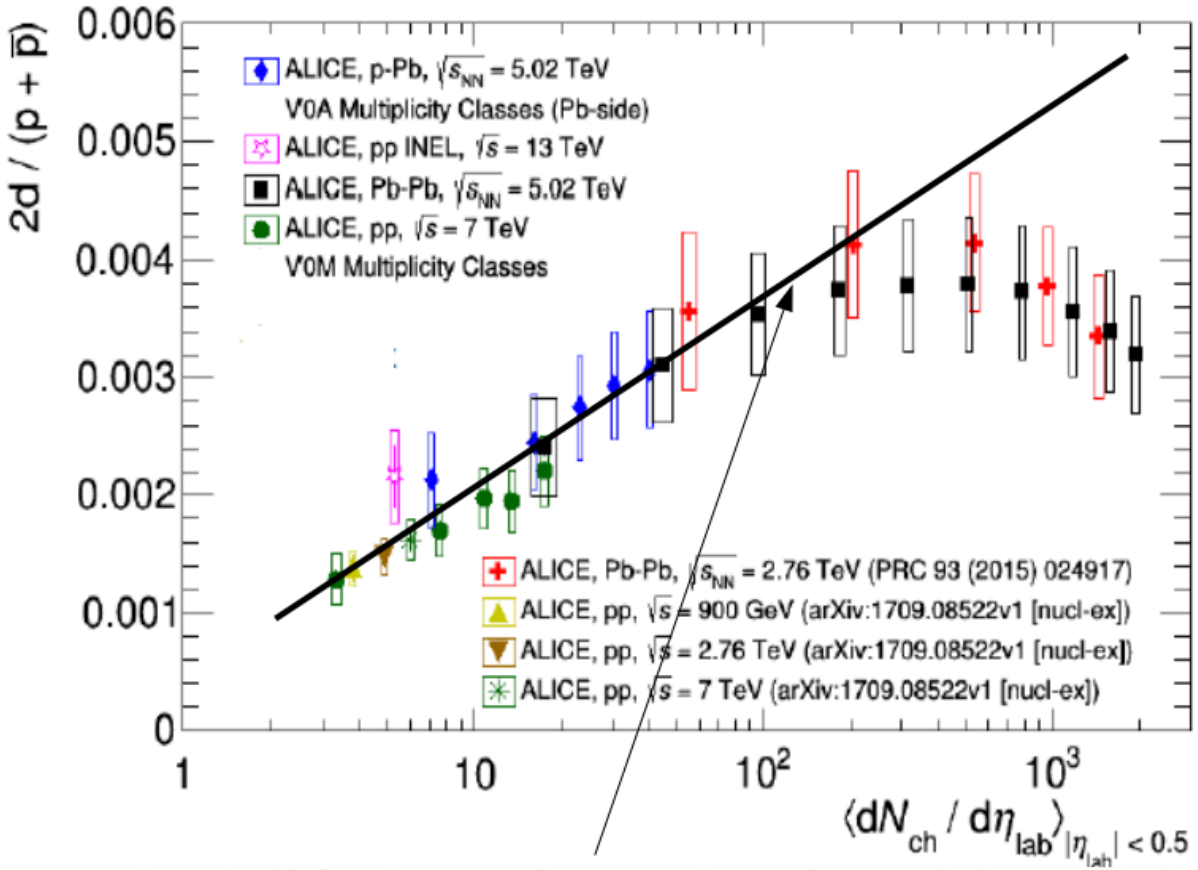
Pb+Pb minimum bias
(ALICE)



Modifications versus Centrality also seen in ALICE deuteron production

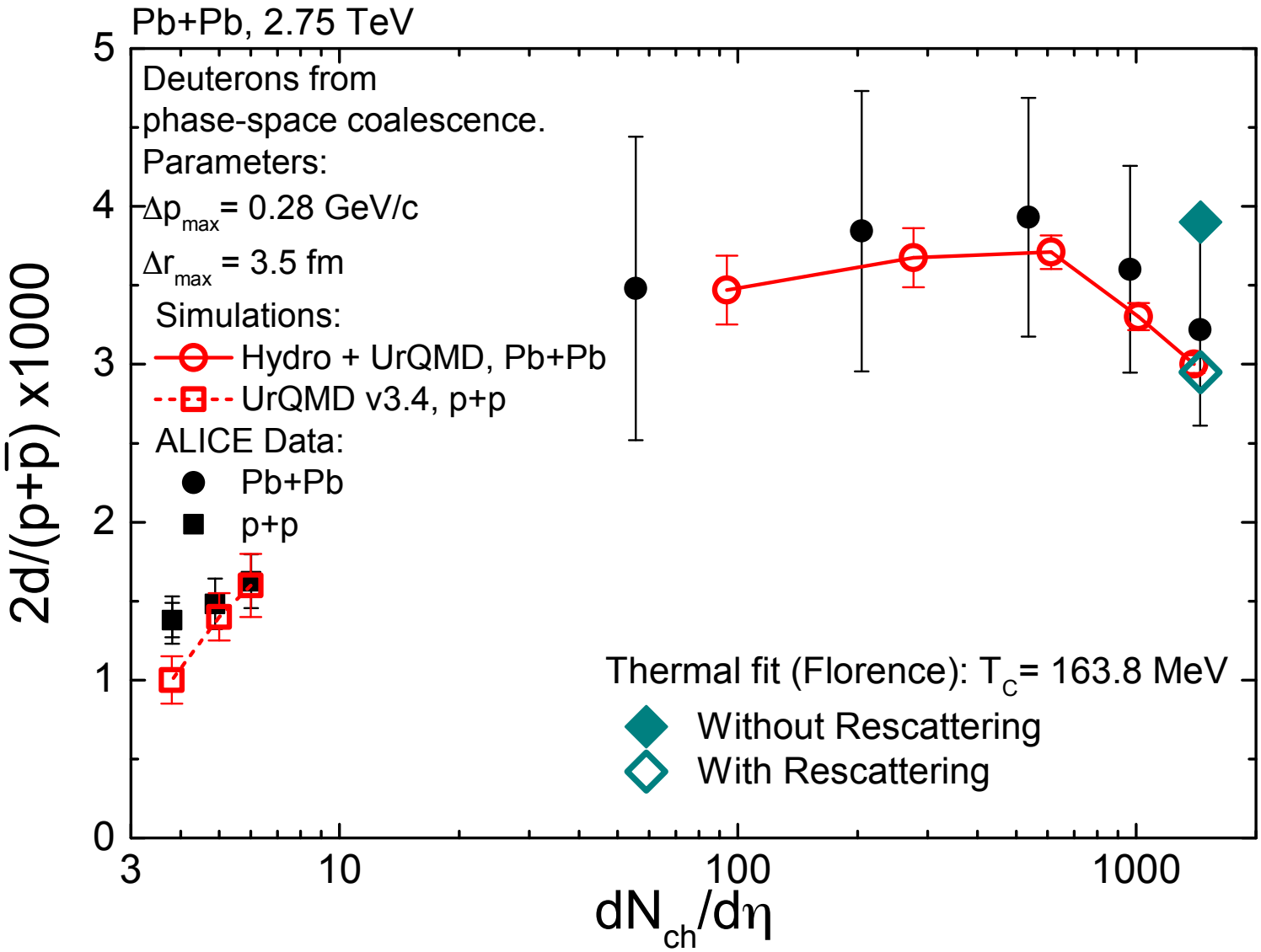
deuteron/proton ratio vs charged-particle multiplicity

EMMI Workshop
Feb. 2018
P. Braun-Munzinger



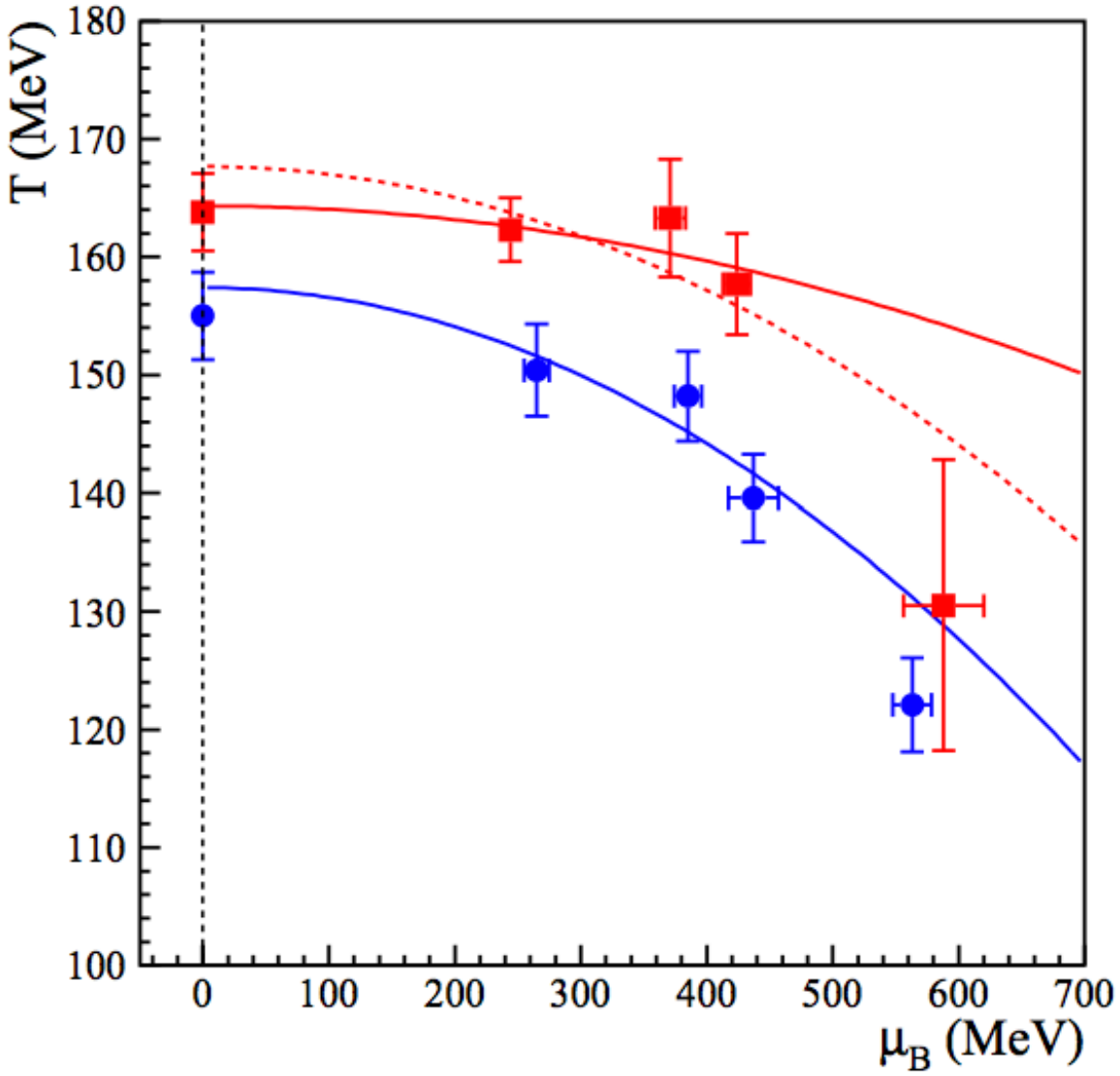
d/p ratio not consistent with 'coalescence' expectations where ratio is expected to increase with volume of the fireball
see, e.g., S. Mrowczynski, arXiv:1607.02267

Coalescence in UrQMD and SHM



The QCD Phase Boundary revisited

F.Becattini et al.,
arXiv:1605.09694



The Alternative: Overlap between Lattice and HRG

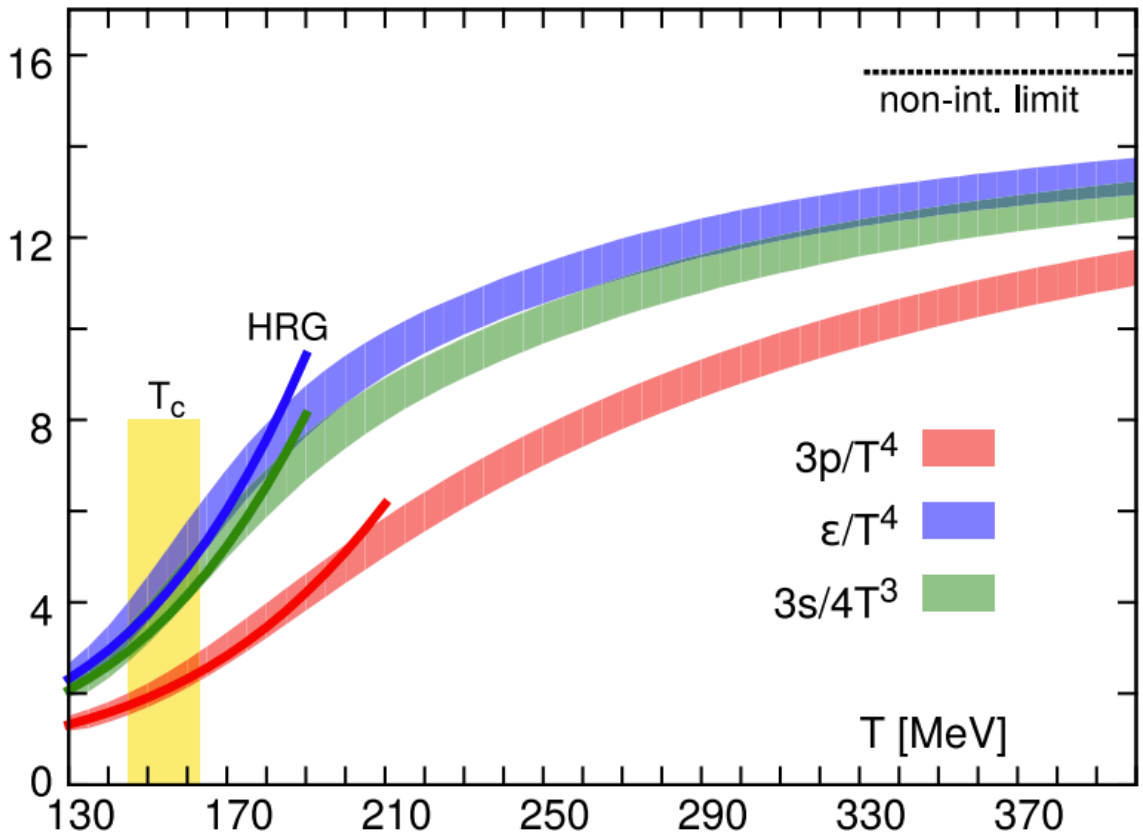
Tensions concerning T_c

- We report T(c)=164MeV, similar to e+e- -> hadrons

- Lattice matching to Hadron Gas (HRG) reports T(c)=150MeV

A. Bazavov et al. , PRD 90 (2014)

A. Bazavov et al. , PRL 113 (2014)



Open Question! Recall the Crossover situation!