Hadronization: Does the Statistical Model Freeze-Out Curve meet the Lattice Parton-Hadron Phase Boundary?

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Motivation

Lattice QCD extrapolation to finite μ_B predicts the parton-hadron coexistence line in the (T,μ_B) plane.

Assumptions:

- Hadronization creates chemical equilibrium freeze-out.
- Hadron abundances freeze out directly at QCD hadronization(?), and survive the hadronic expansion stage(?).

Under these assumptions:
Statistical Model (SM) freeze-out curve locates the QCD phase boundary curve.

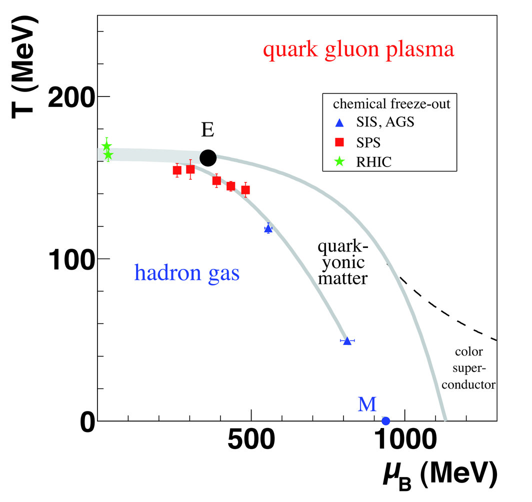


Fig. 1: Phase diagram of QCD matter

Our aim: Consider the "Empirical freeze-out curve" [1,2].

Questions:

- Why does the freeze-out curve appear to fall below the lattice curve at higher μ_B?
- Does the hadronic expansion phase REALLY preserve the hadronic multiplicity distribution?

Hadronic Expansion Effects

UrQMD Study of Hadronic Expansion Effects on Hadron Yields

- Employ the recent hybrid version [3] of UrQMD: Hydrodynamic (3+1) phase until energy density < 1 GeV/fm^3, plus hadronic emission à la Cooper-Frye. Attach UrQMD hadronic expansion as an "afterburner" stage.
- Compare hadronic yields directly after Cooper-Frye with those after the "afterburner" stage.

SERIOUS ANNIHILATION EFFECTS in baryon and antibaryon sector!

- At SPS: selective annihilation of $\bar{p}$, $\bar{\Lambda}$ and $\bar{\Xi}$. The rest essentially unaffected.
- At RHIC and LHC: annihilation tends to be symmetric for baryons and antibaryons; $\Lambda/\bar{\Lambda}$ unaffected, while Ω and $\bar{\Omega}$ are enhanced.

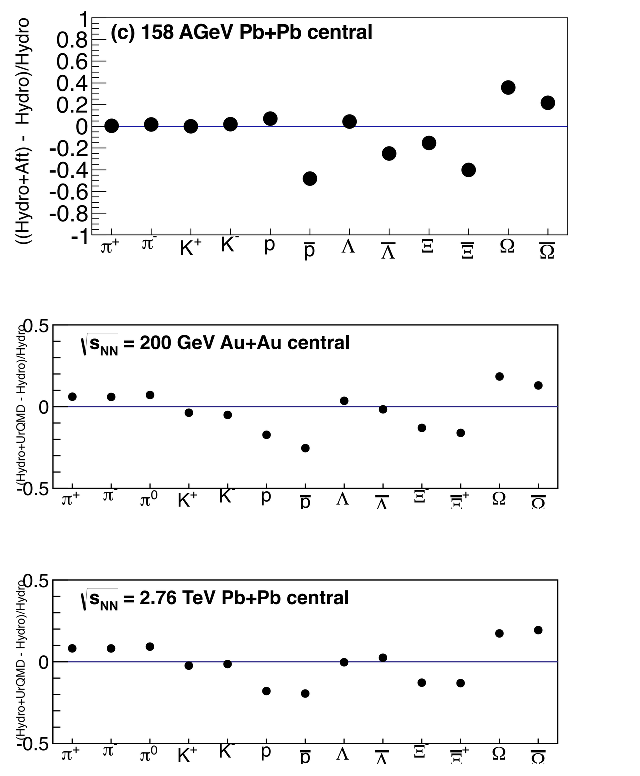


Fig. 2: "Survival Plots" at top SPS [2], top RHIC and top LHC [4] energies in central collisions

Statistical Model Analysis

UrQMD at SPS Energies

Approach:

- Fit SM to UrQMD "Hydro only"
- Fit SM to UrQMD "Hydro plus afterburner"

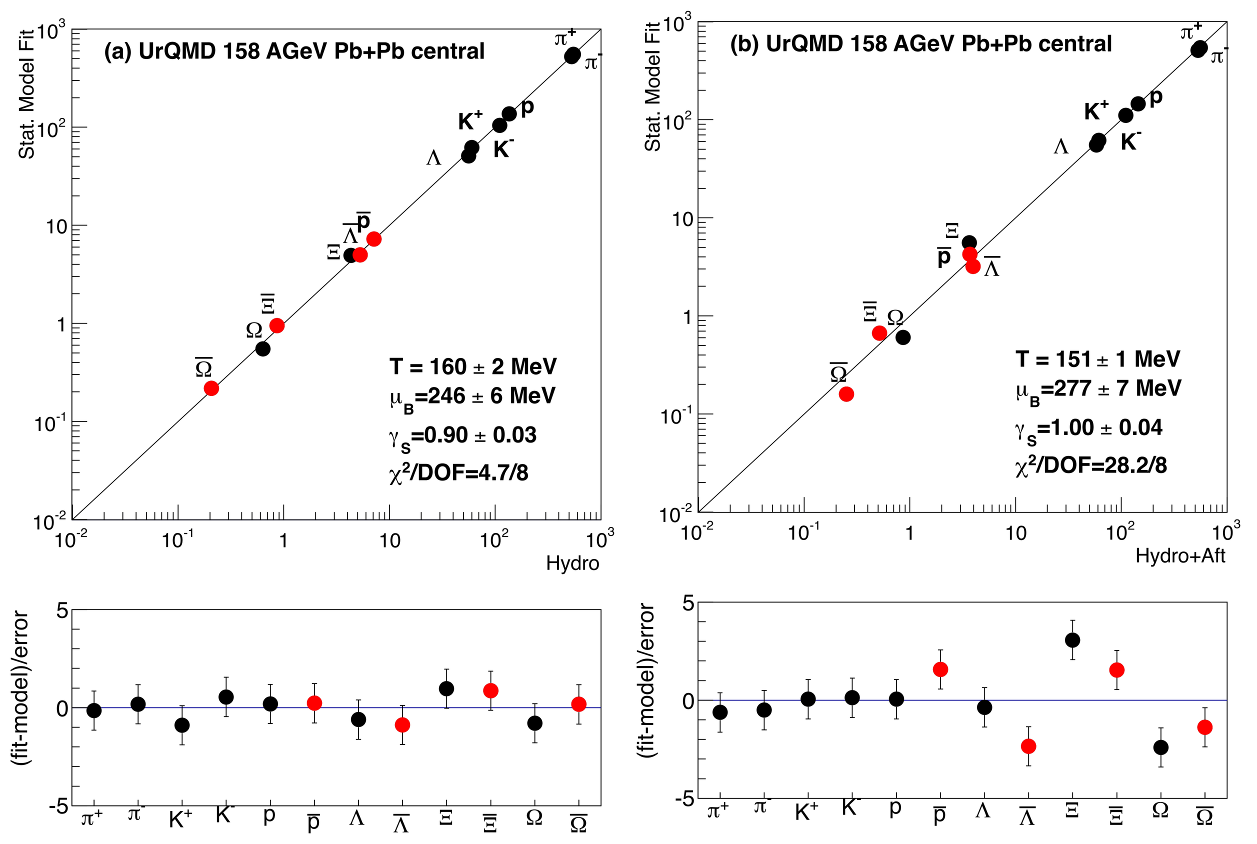


Fig. 3: Statistical model fit to model calculations at $\sqrt{s}$ = 17.3 GeV (a) before and (b) after the afterburner phase.
FIT DETERIORATES (SIGNIFICANTLY) WITH AFTERBURNER PHASE

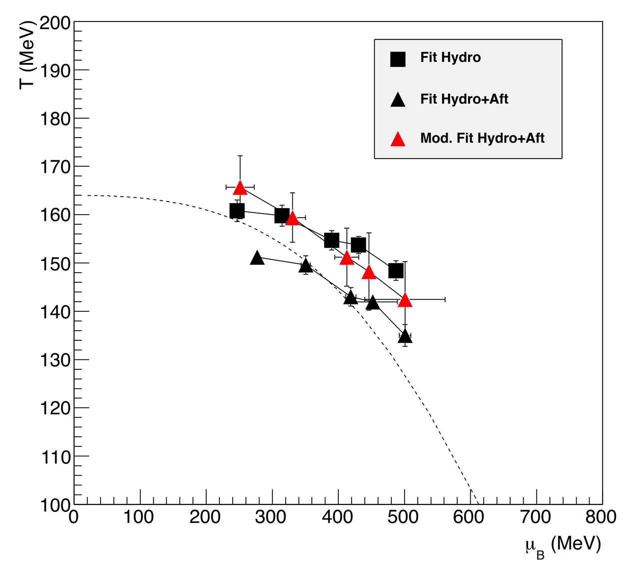


Fig. 4: The resulting SM freeze-out points in the (T,μ_B) plane:
DOWNWARD SHIFT OF FREEZE-OUT CURVE BY CASCADE STAGE by about 10-15 MeV.
Also illustrated: SM fits to UrQMD (Hydro plus afterburner) EXCLUDING $\bar{p}$, $\bar{\Lambda}$ and $\bar{\Xi}$: The freezeout curve moves upward again (possible remedy?!).

→ The empirical freeze-out curve needs revision

NA49 Data

SM fit to NA49 data [5] in full acceptance central Pb+Pb 17.3 GeV OMITTING $\bar{p}$, $\bar{\Lambda}$ and $\bar{\Xi}$ from the fit (see [2] for details).

STRIKING SIMILARITY to UrQMD survival plot in Fig. 2.
Thus, data shows similar selective antibaryon deficits as predicted by UrQMD.

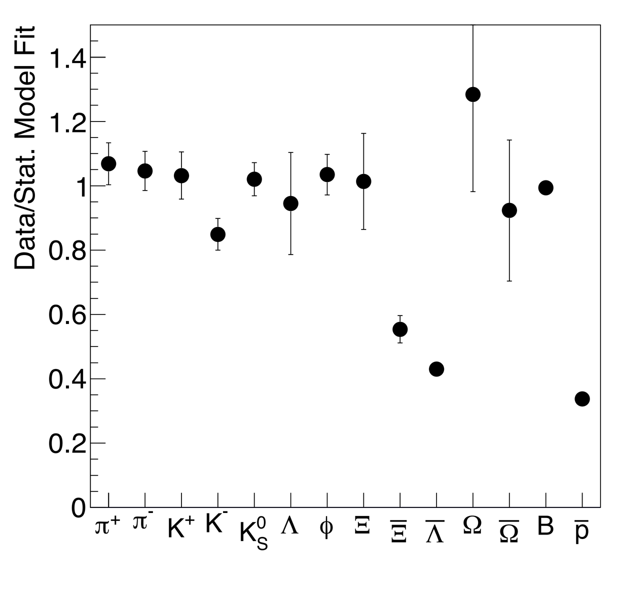
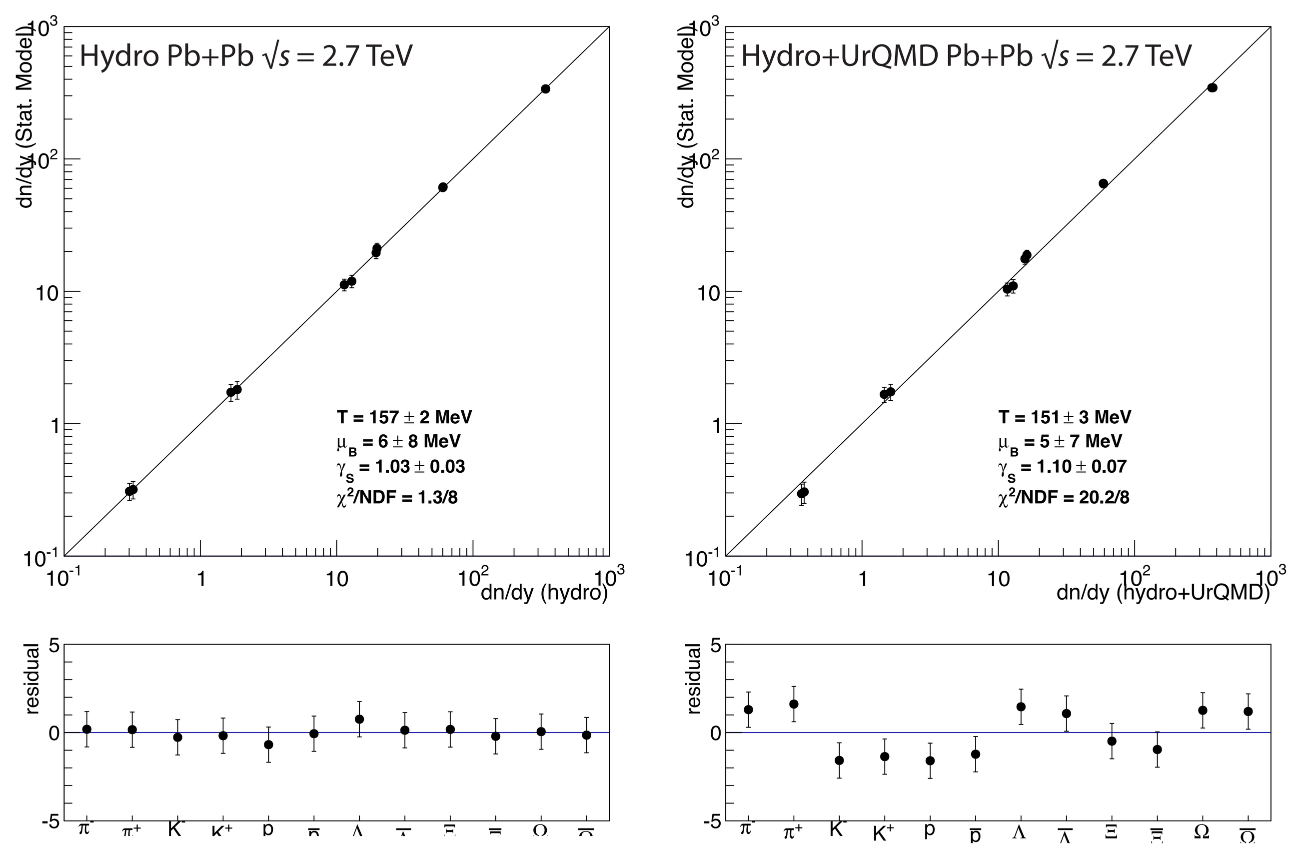


Fig. 5: Relative deviation of hadron multiplicities measured in Pb+Pb collisions at $\sqrt{s}$ = 17.3 GeV from statistical model fit results.

UrQMD at LHC Energy

Similar UrQMD plus statistical model analysis applied to central Pb+Pb collisions at $\sqrt{s}$ = 2.7 TeV.



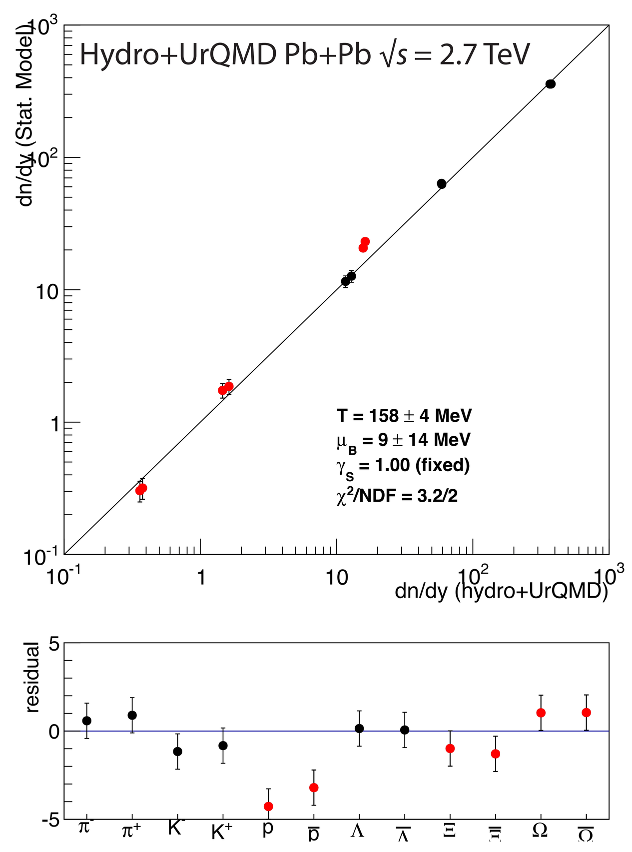


Fig. 6: Top left panel: SM fit to hydro only at $\sqrt{s}$ = 2.7 TeV. Top right panel: SM fit to hydro + UrQMD afterburner at $\sqrt{s}$ = 2.7 TeV. Left panel: SM fit to hydro + UrQMD afterburner at $\sqrt{s}$ = 2.7 TeV excluding p, $\bar{p}$, Ξ, $\bar{\Xi}$, Ω, $\bar{\Omega}$ from the fit, as suggested by the survival plot in Fig. 2 (SM predictions for those particles are shown as red points).

The obtained (T,μ_B) with a fit to a suitably restricted hadron sample is close to the hadronization point.

Conclusions

- The hadronic expansion phase does IN FACT distort the hadrochemical equilibrium created at hadronization.
- Indeed, in statistical model fits to UrQMD, the final state (afterburning) effects cause a general downward shift in the (T,μ_B) positions of the chemical freeze-out points, by about 10-15 MeV [2] in the SPS energy range. At the LHC, the predicted shift in temperature is of the order of 6-8 MeV with sizeable discrepancies of $\bar{p}$, $\bar{\Xi}$ and $\bar{\Omega}$.
- The resulting chemical freeze-out curve thus needs revision.

A refined data analysis with the SM will result in a modified freeze-out curve that will more closely follow recent lattice calculations [6].

References

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