Probing the Extremes of Matter with Heavy Ions
Erice-Sicily: 16-24 September 2012

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

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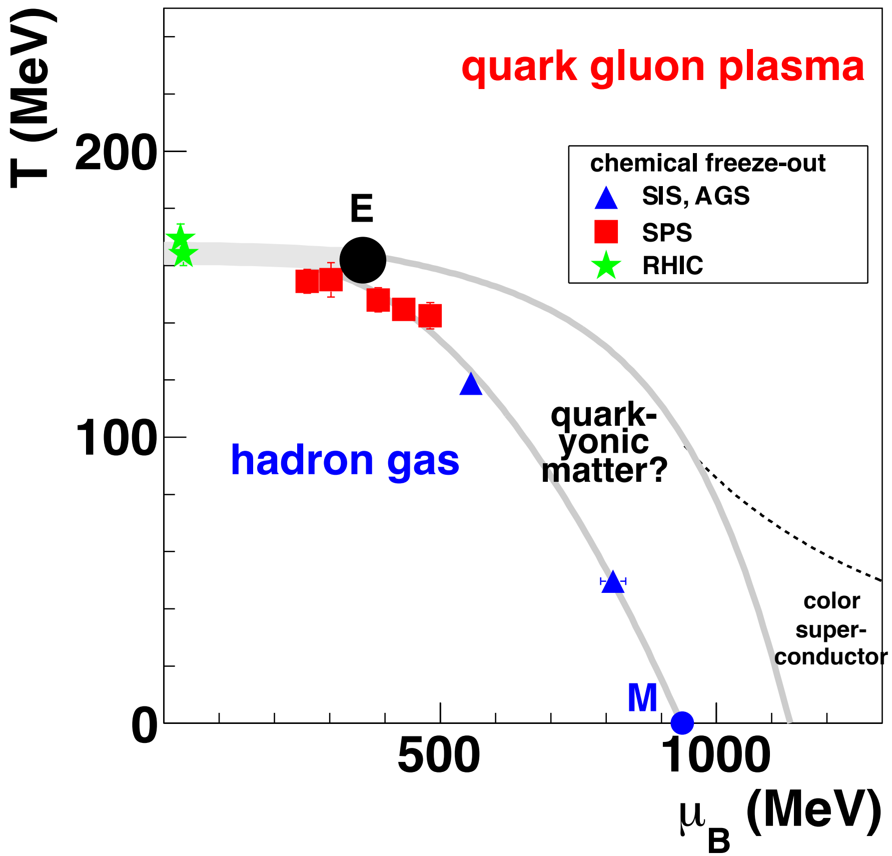
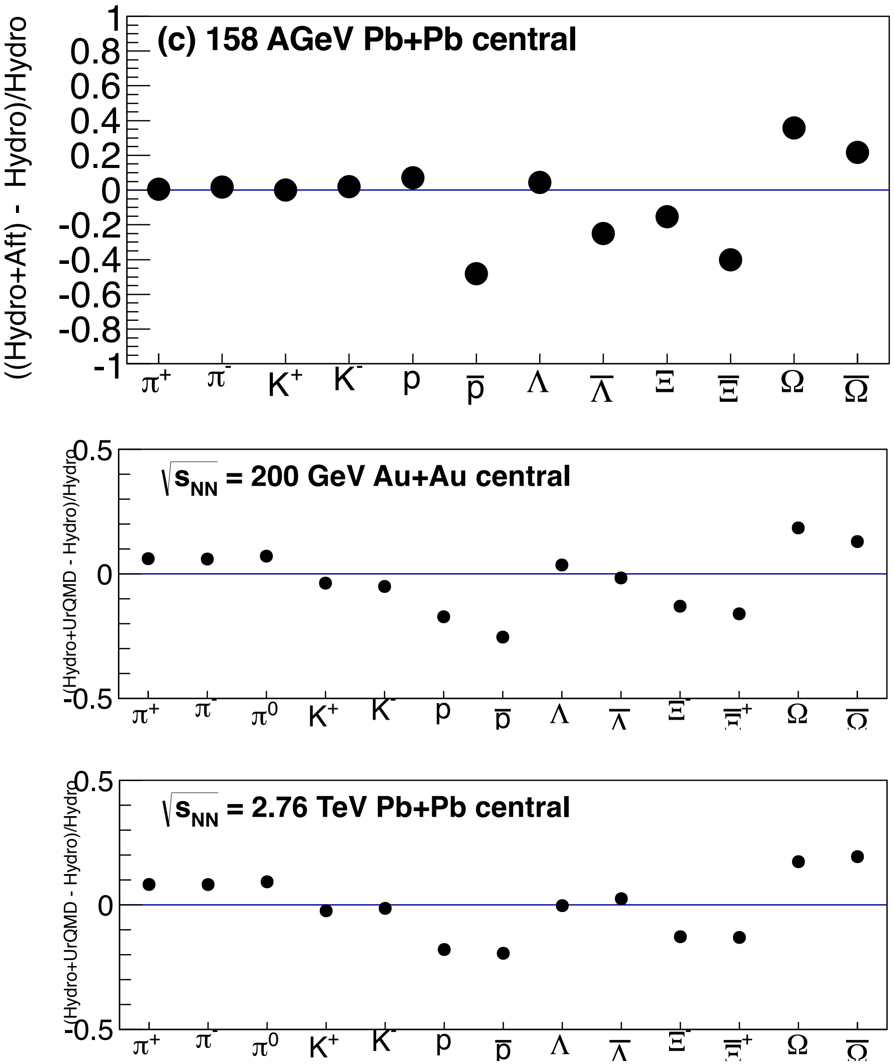
Sketch of the QCD Phase Diagram

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.
- Our aim: Consider the "Empirical freeze-out curve"
- 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?

UrQMD Study of Hadronic Expansion Effects on Hadron Yields



- Employ the recent hybrid version of UrQMD:
  - Hydrodynamic (3+1) phase until energy density < 1 GeV/fm3, 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!

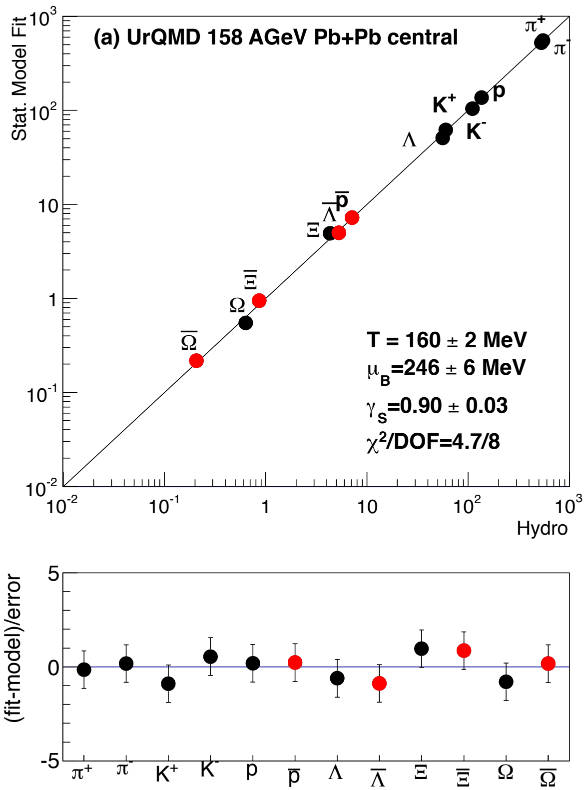
- At SPS: selective annihilation of $\bar{p}$, $\bar{\Lambda}$ and $\bar{\Xi}$. The rest essentially unaffected.

- At RHIC and LHC: annihilation tends to be symmetric for baryons and antibaryons; $\Lambda/\bar{\Lambda}$ unaffected, while Ω and $\bar{\Omega}$ are enhanced.

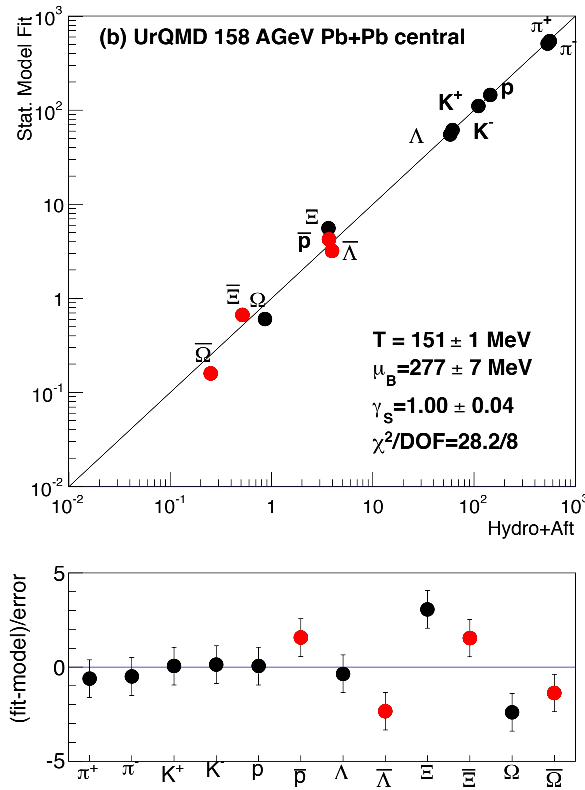
Statistical Model Analysis: UrQMD at SPS Energies

Approach: SM fit to UrQMD "Hydro only" vs. "Hydro plus afterburner"

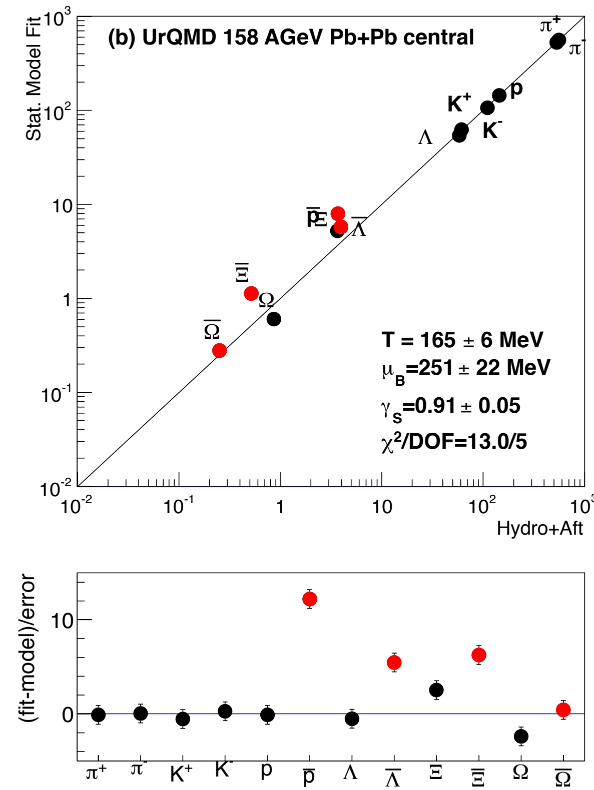
Hydro only



Hydro plus afterburner



Hydro plus afterburner restricted hadron set

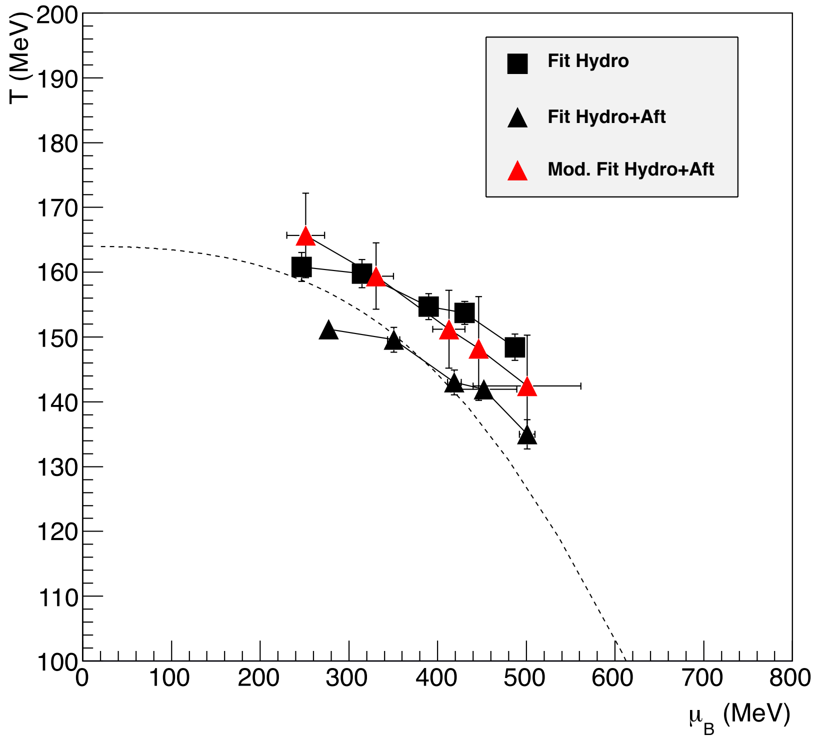


→ The empirical freeze-out curve needs revision!

Statistical Model Analysis: UrQMD at SPS Energies

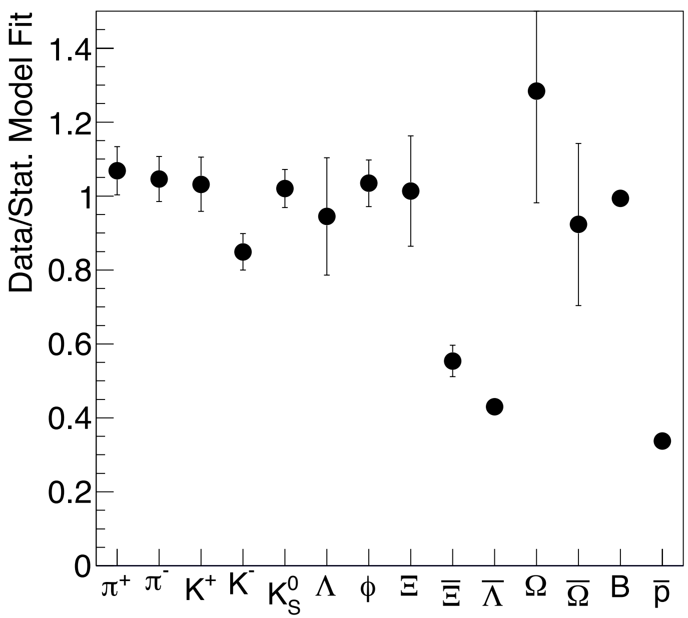
Approach:

- SM fit to UrQMD "Hydro only"
- SM fit to "Hydro plus afterburner"
- SM fit to "Hydro plus afterburner" with restricted hadron set

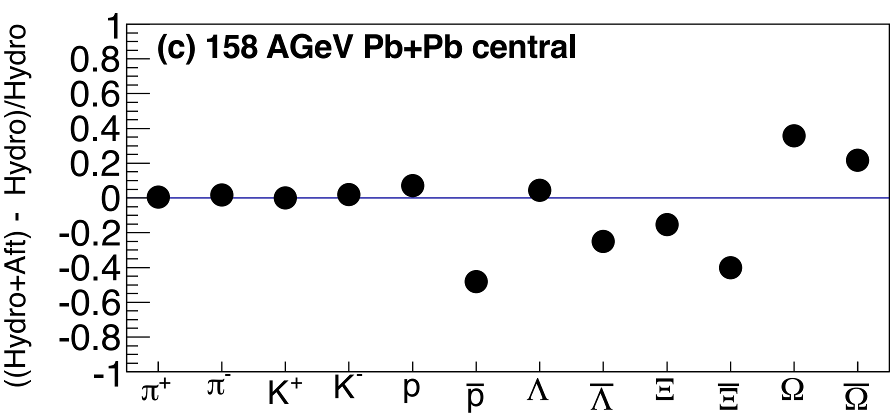


A modified SM fit recovers the original freeze-out curve, the empirical freeze-out curve will move up in *T*

Statistical Model Analysis: NA49 Data



SM fit to NA49 data in full acceptance central Pb+Pb 17.3 GeV OMITTING $\bar{p}$, $\bar{\Lambda}$ and $\bar{\Xi}$ from the fit

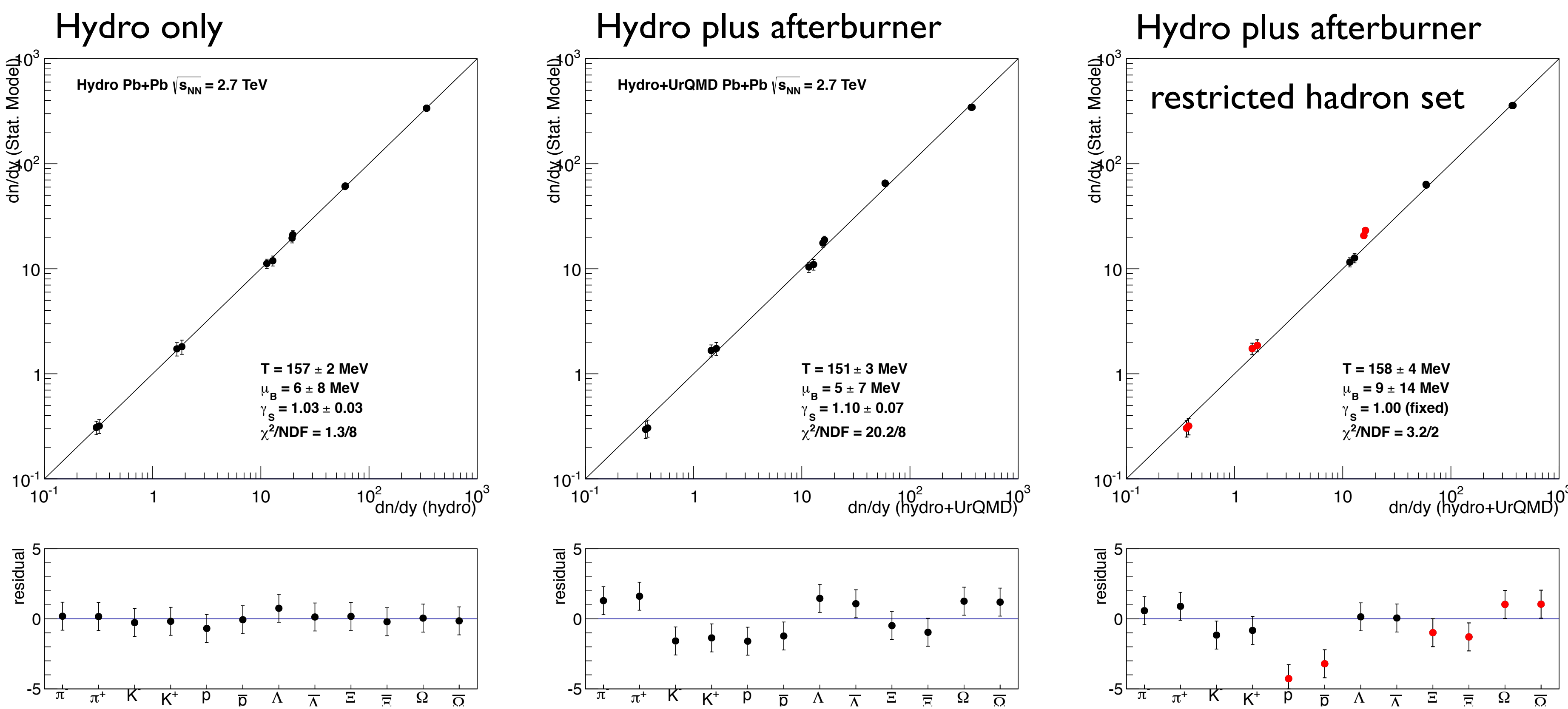


STRIKING SIMILARITY to UrQMD survival plot

Data shows similar selective antibaryon deficits as predicted by UrQMD

Statistical Model Analysis: UrQMD at LHC Energy

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



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

Conclusions 1

- 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 in the SPS energy range. At the LHC, the predicted shift in temperature is of the order of 6-8 MeV with sizable discrepancies of p, $\bar{p}$, Ξ, $\bar{\Xi}$, Ω and $\bar{\Omega}$.

- The resulting chemical freeze-out curve thus needs revision.

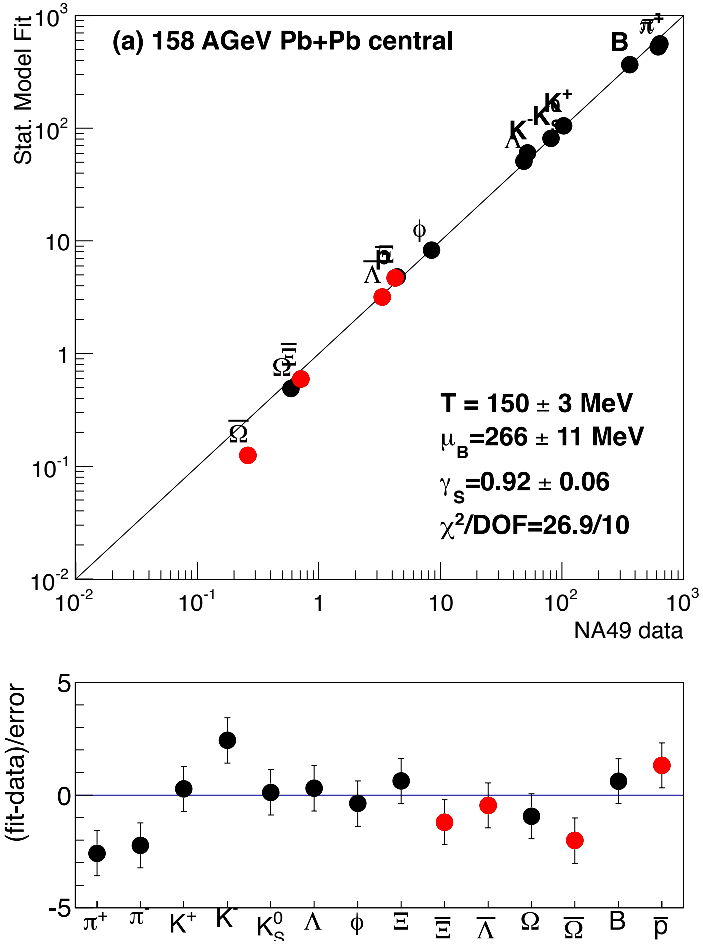
- A refined data analysis with the SM will result in a modified freeze-out curve that will more closely follow recent lattice calculations

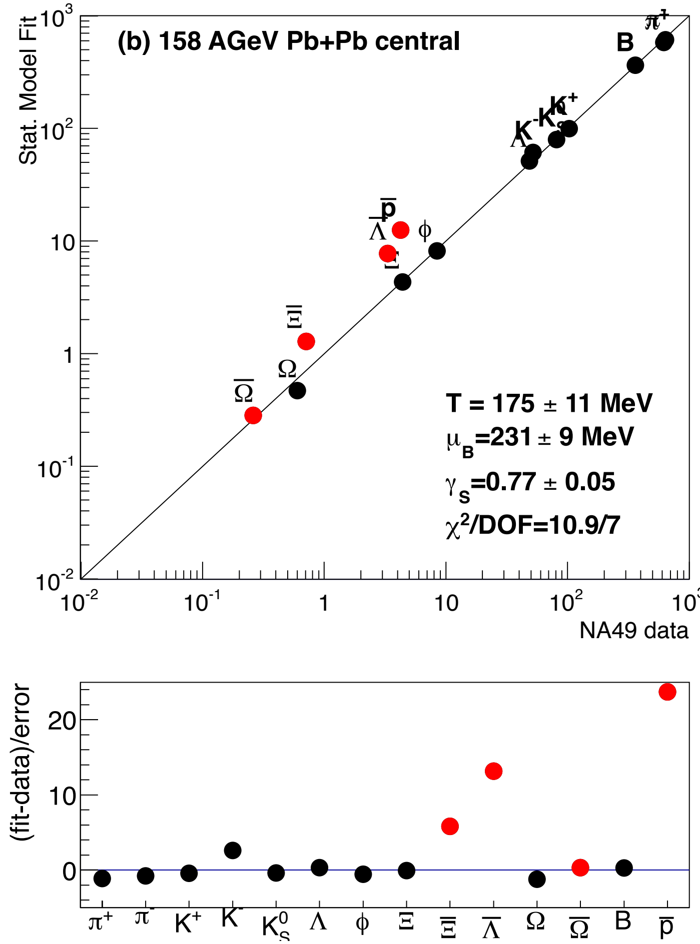
- Look at data

For details on the method, see:
- F. Becattini et al., PRC 85 (2012) 044921
- J. Steinheimer et al., arXiv:1203.5302

Statistical Model Analysis: NA49 Data

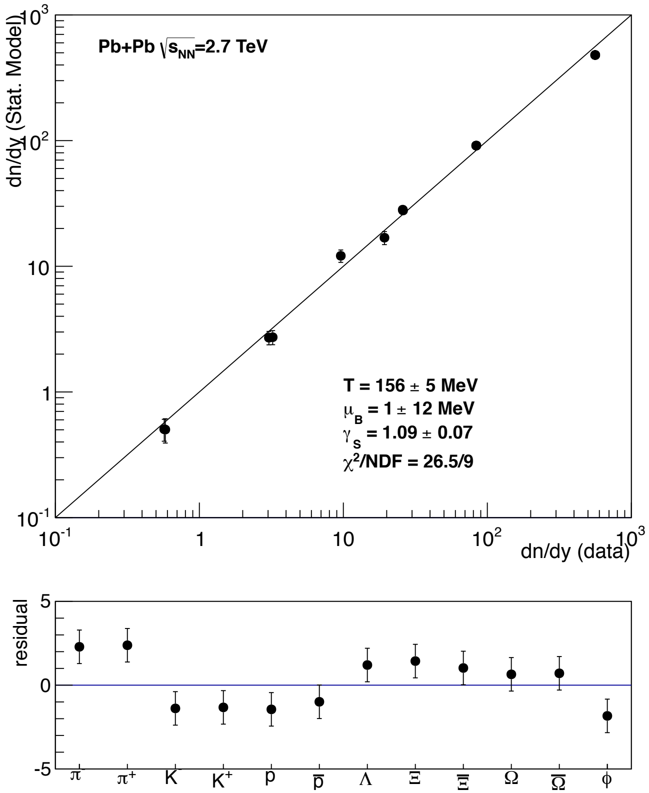
Approach: usual SM fit vs. fit omitting $\bar{p}$, $\bar{\Lambda}$ and $\bar{\Xi}$



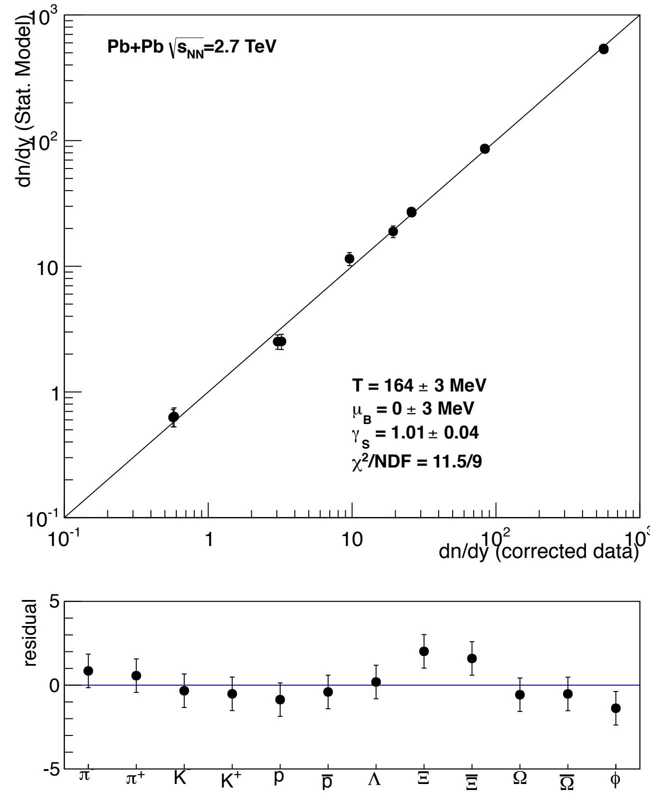


Statistical Model Analysis: ALICE Data

Standard SM fit



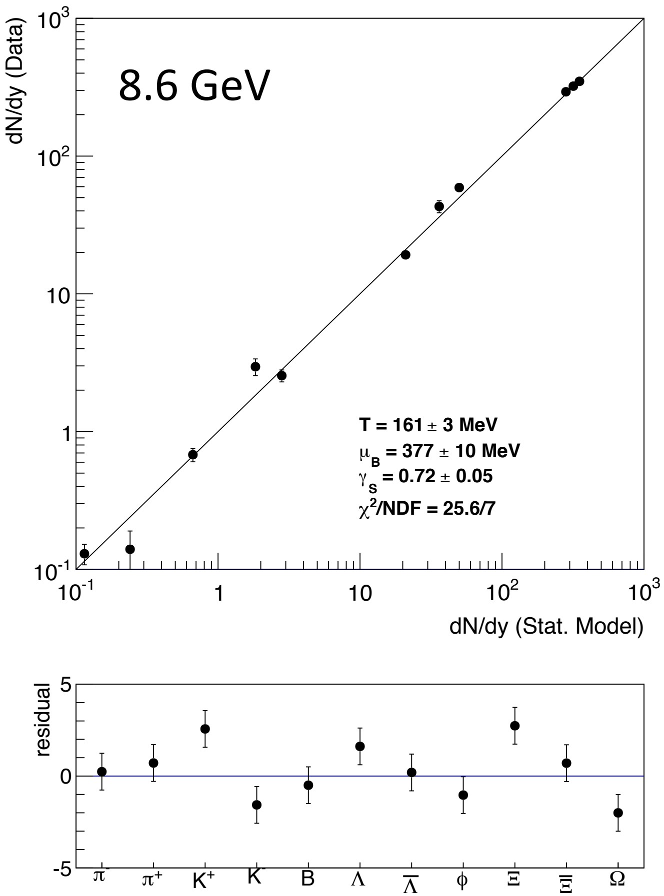
Apply correction factors

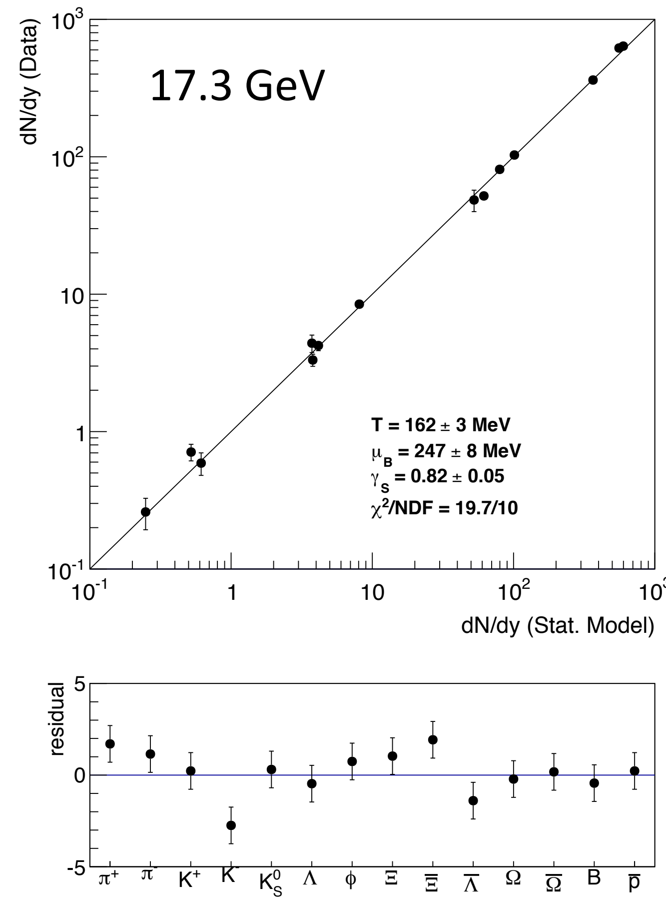


Data: ALICE collaboration, preliminary Quark Matter 2012

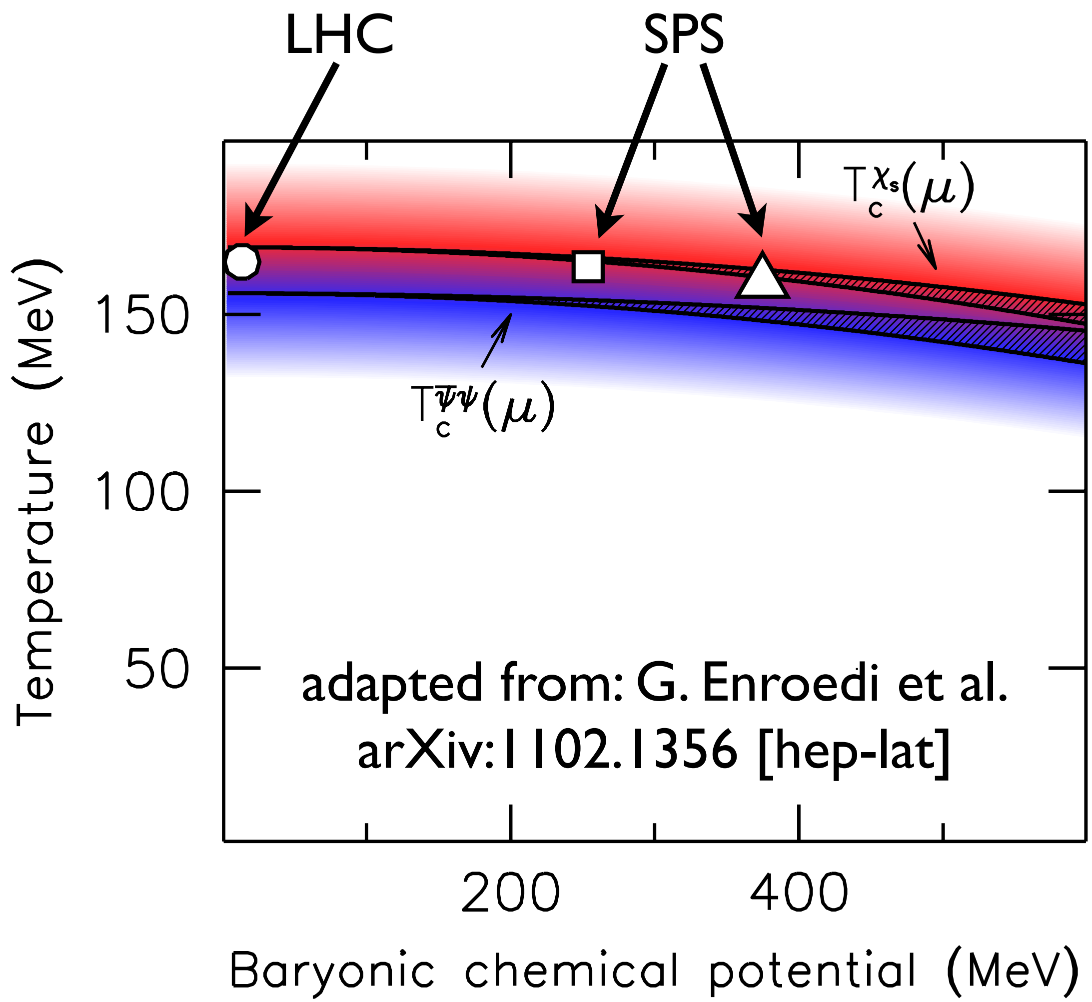
Statistical Model Analysis: NA49 Data

Apply correction factors





Freeze-out revisited:
The Phase Diagram



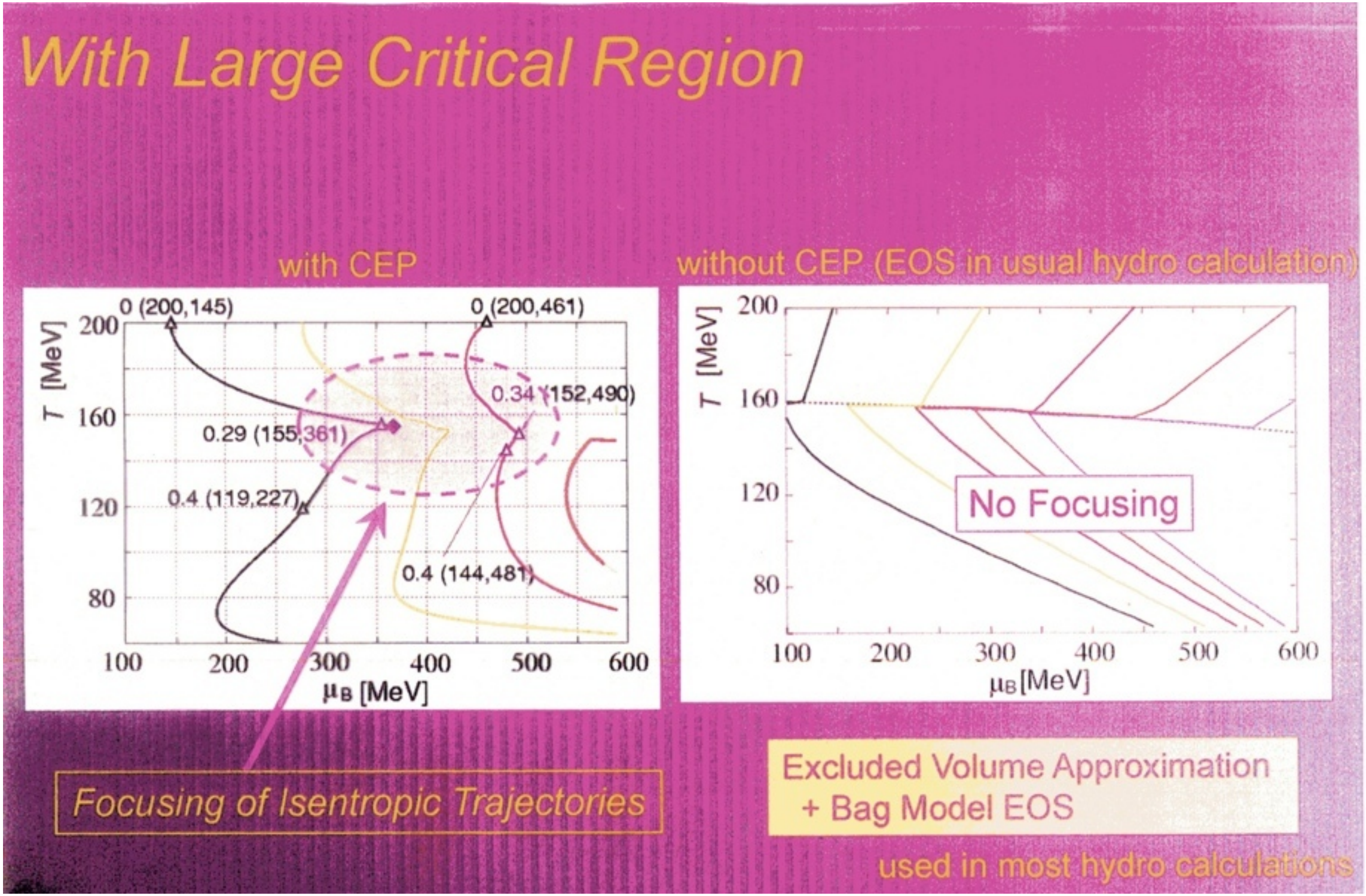
Conclusions 2

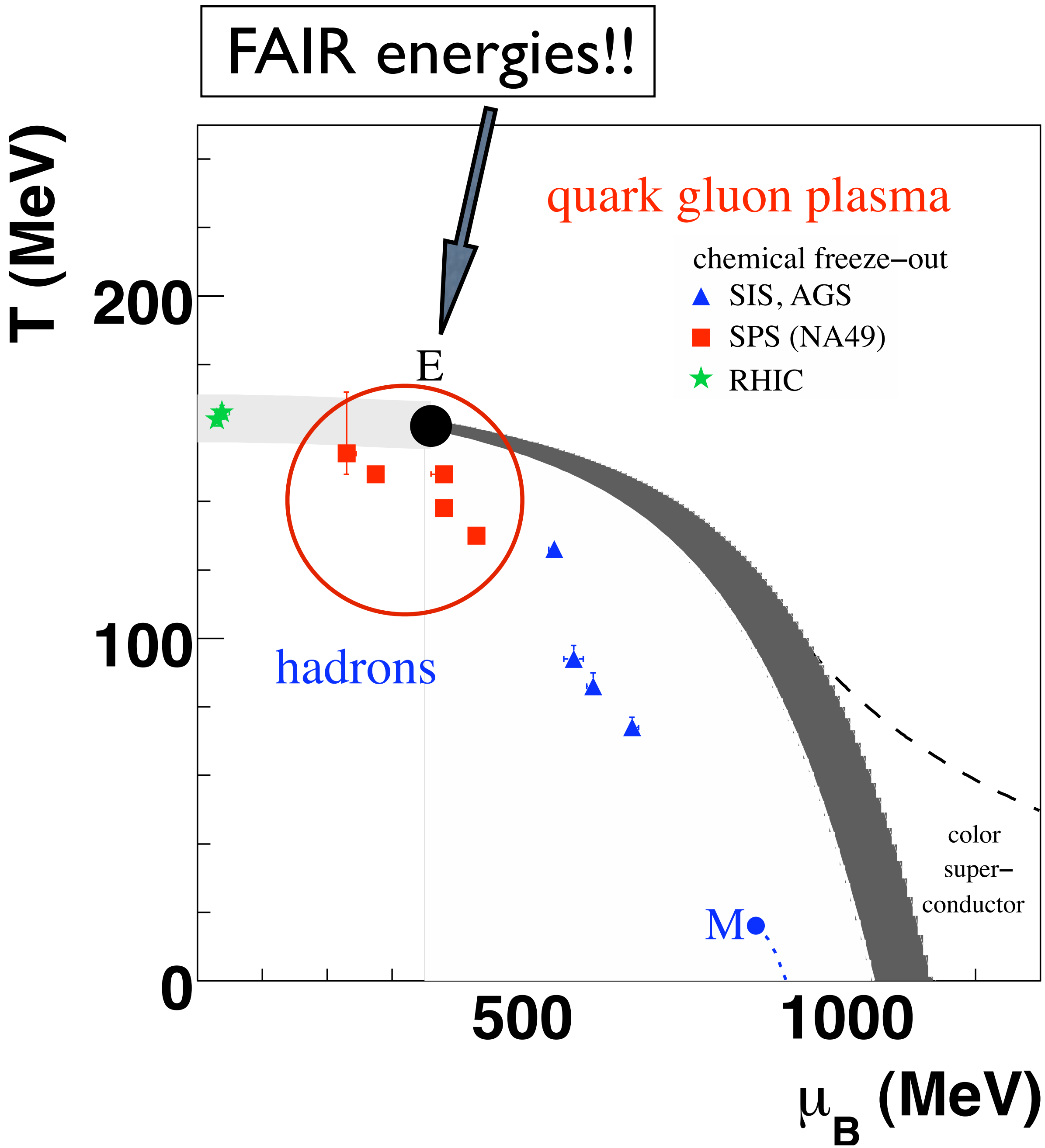
- The corrected curve intends to reconstruct the hadronization points
- It coincides with the lattice parton-hadron transition line up to μ_B = 400 MeV
- Hadronization occurs from a Quark-Gluon Plasma
- The "onset of deconfinement" must be at $\sqrt{s}$ below 8 GeV

Back up

Investigation of the lattice coexistence line

Asakawa and Nonaka: Focusing by critical point





A. Andronic, P. Braun-Munzinger, J. Stachel 0812.1186 [nucl-th]