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Does the chemical freeze-out line meet a phase boundary?

F.B., T. Koellegger, M. Mitrovski, T. Schuster, R. Stock and M. Bleicher
Hadronization and hadronic freeze-out
in relativistic nuclear collisions
Phys. Rev. C 85 (2012) 044921

OUTLINE

- Introduction
- Chemical freeze-out of a hydro+Urqmd simulation
- A test on SPS data
- Conclusions

Motivations

Question: is the chemical freeze-out line a “critical” line?

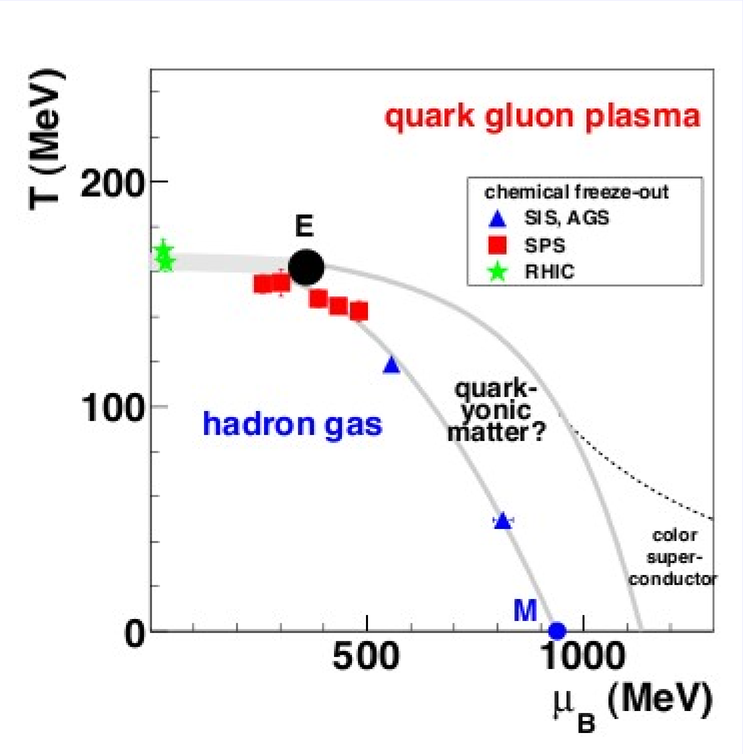
If all particle species freeze-out at at the same T-μ point, one may argue that hadronization and chemical freeze-out coincide, hence ChemFO defines a phase boundary

A. Andronic et al., Nucl. Phys. A 837 (2010) 65

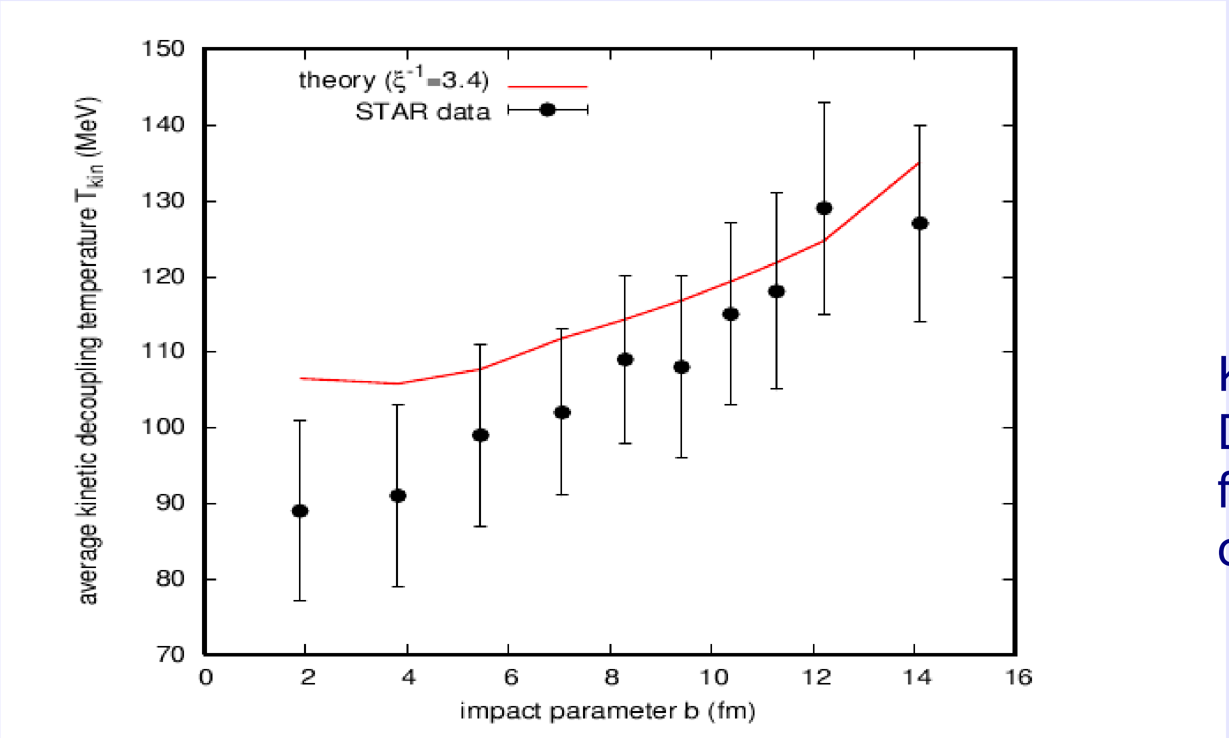
At RHIC energies, chemical freeze-out was shown [45] to take place very close (within less than about 10 MeV) to the phase boundary, driven by the rapid density change across the phase transition. Further it was argued that freeze-out ends when the system is fully hadronized, i.e. at low density in the hadronic phase. Were this not the case [46], one would also expect different freeze-out parameters for each hadron species due to widely different hadronic cross sections. This is not observed. We believe this argument to be generic [45]: to ensure simultaneous (within a very small interval in temperature and chemical potential) freeze-out of all hadrons, the freeze-out curve has to be very close to a line with a rapid density change. An immediate consequence of this would be that the chemical freeze-out curve delineates phase boundaries, not only for small values of μ_B but everywhere. But what provides the phase boundary

See also R. Stock et al., arXiv:0911.5705

But what boundary at lower T, where ChemFO is presumably lower than QCD critical line? This phenomenon could be a clue of the existence of another phase (Quarkyonic matter, L. McLerran)

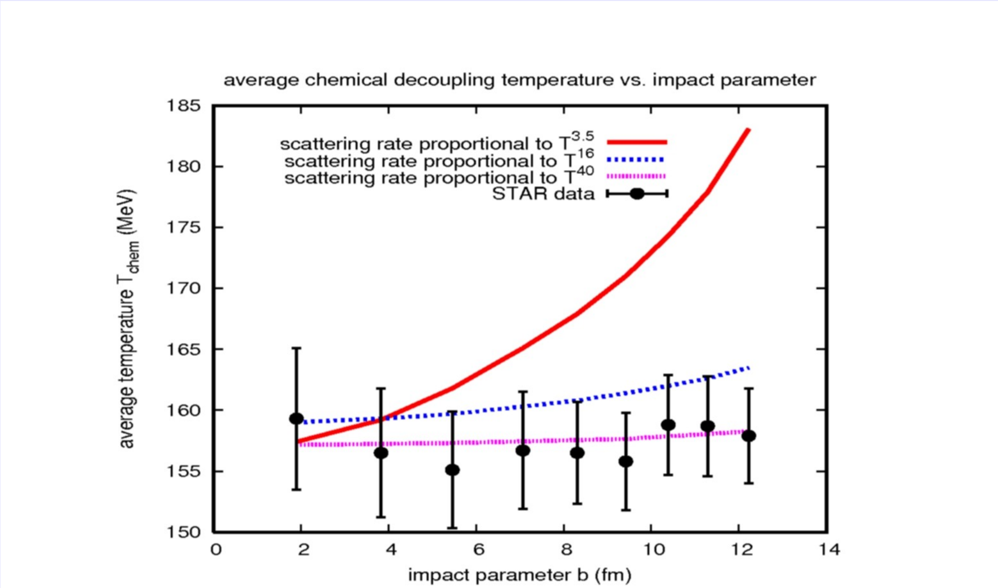


Centrality dependence



Kinetic freeze-out (at RHIC energy) DOES vary significantly as a function of centrality, whereas chemical does not.

U. Heinz, G. Kestin, CPOD 2006
nucl-th: 0612105

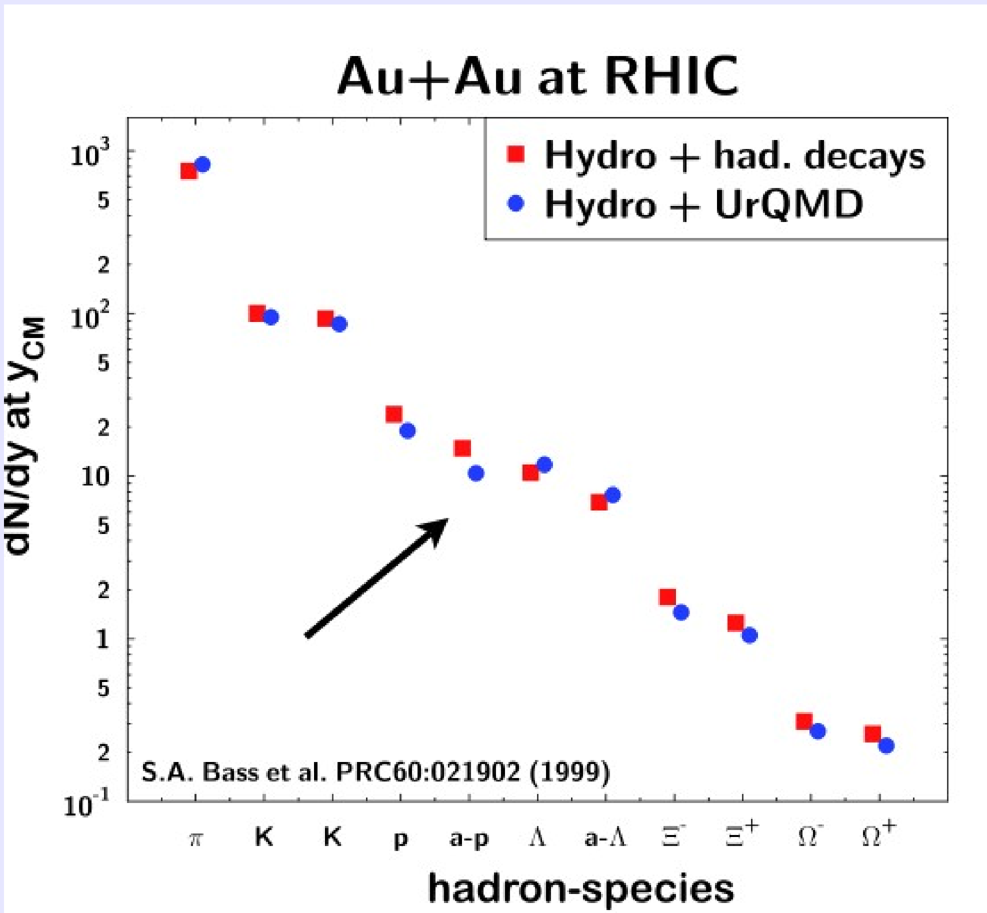


We can test the idea

R. Stock, talk at QM2011, arXiv:1107.1574

- Is the agreement between SHM and data an indication of common freeze-out?

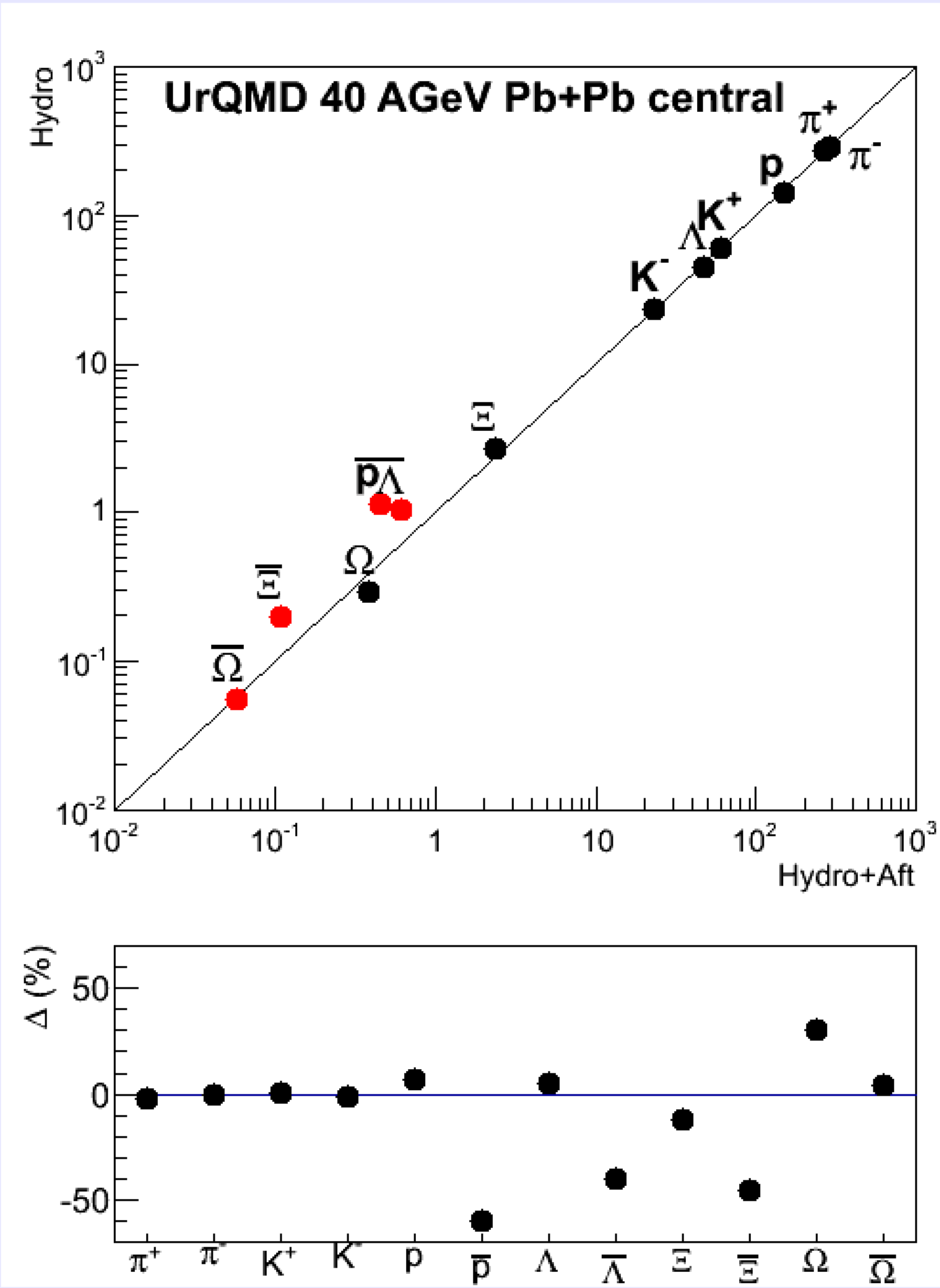
If yes, we should see a deterioration of fit quality to a simulation including post-hadronization inelastic rescattering

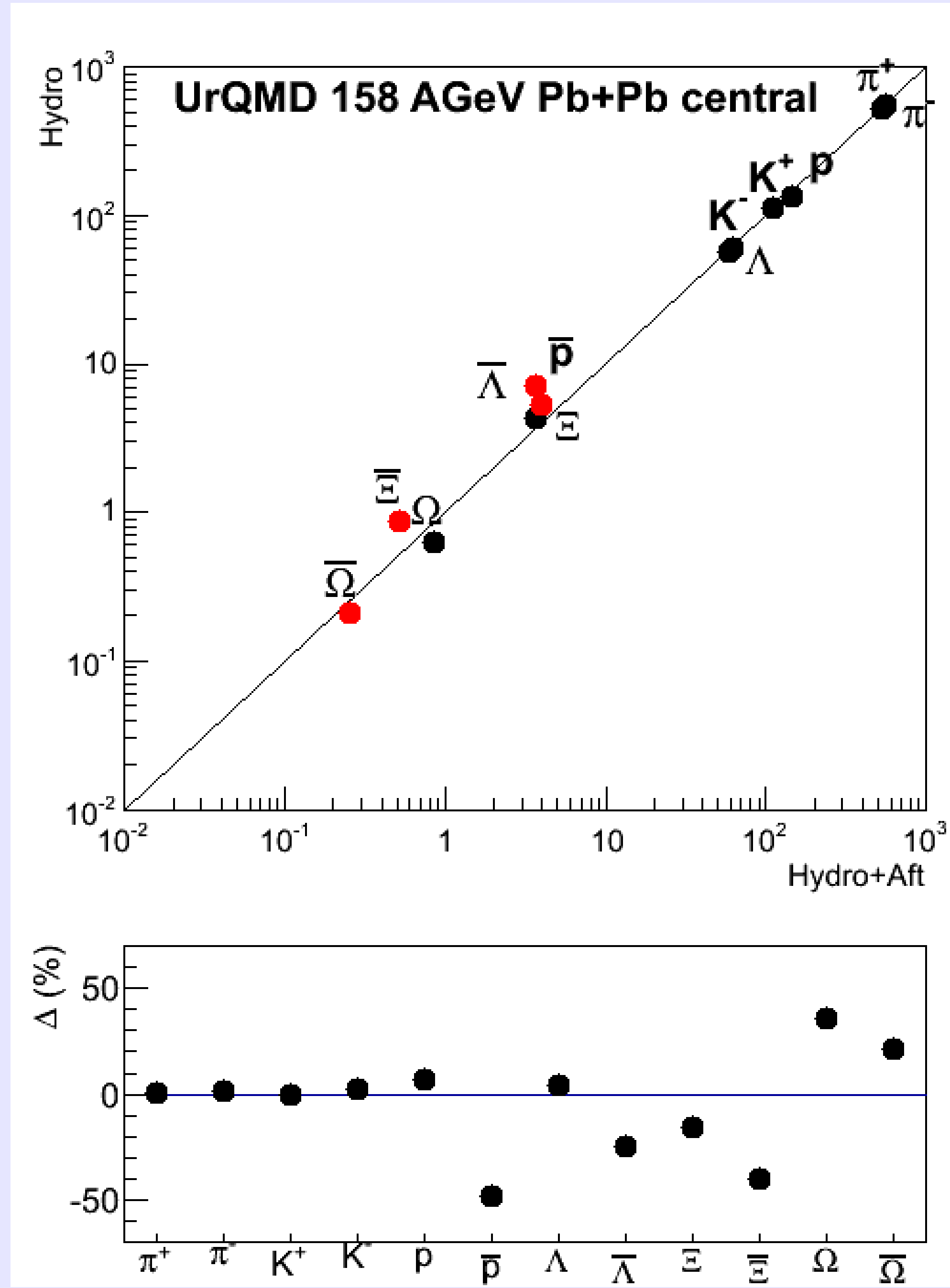


PROGRAMME

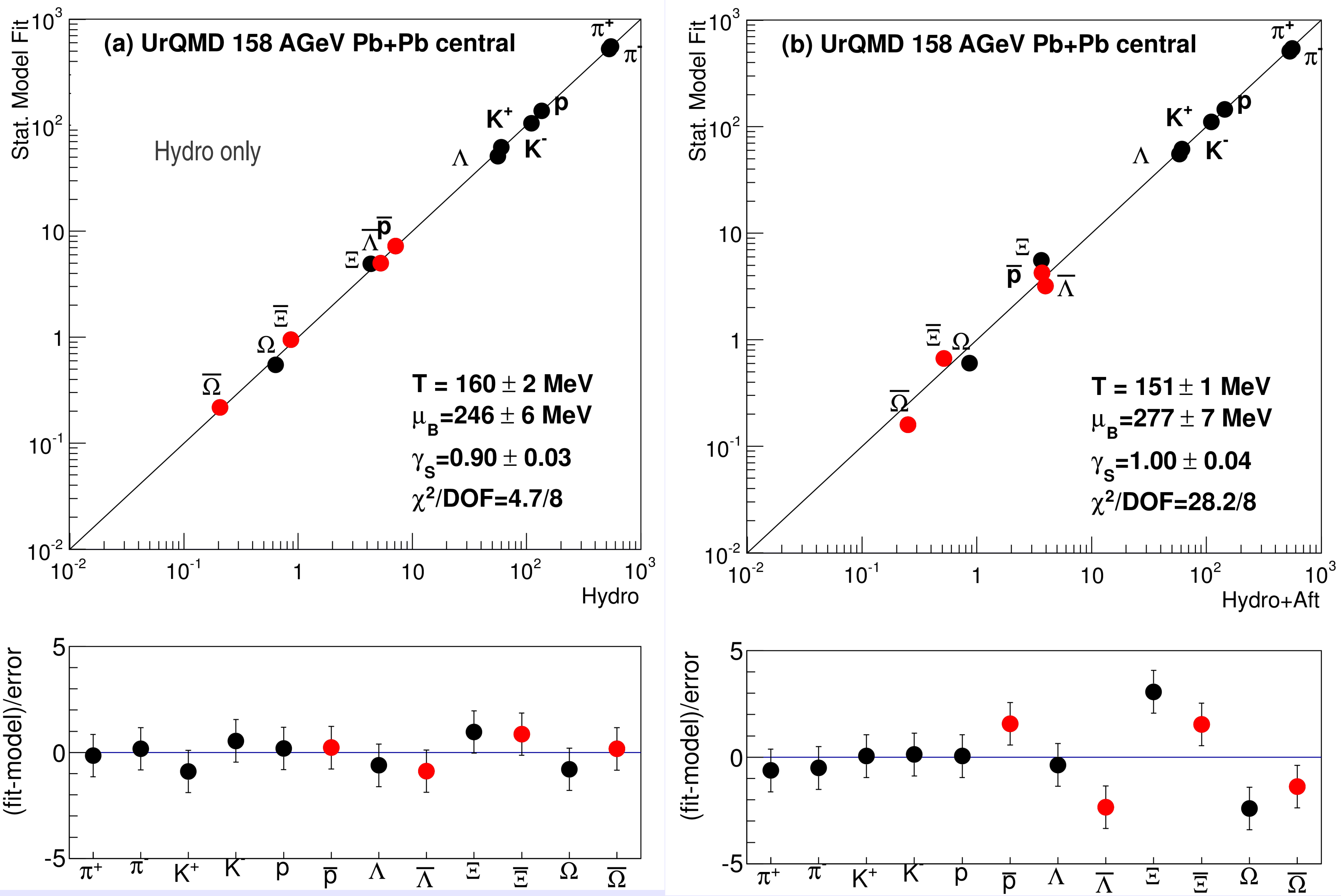
- Employ hybrid transport model with hydro stage and subsequent hadronic cascade, e.g. UrQMD v3.3
- Terminate
  - directly after hydro phase → decay into vacuum
  - or use UrQMD cascade expansion as "afterburner"
- First impression: Bulk hadrons show little change, but effects on anti-baryons

Main effect of hadronic rescattering (afterburner): antibaryon loss



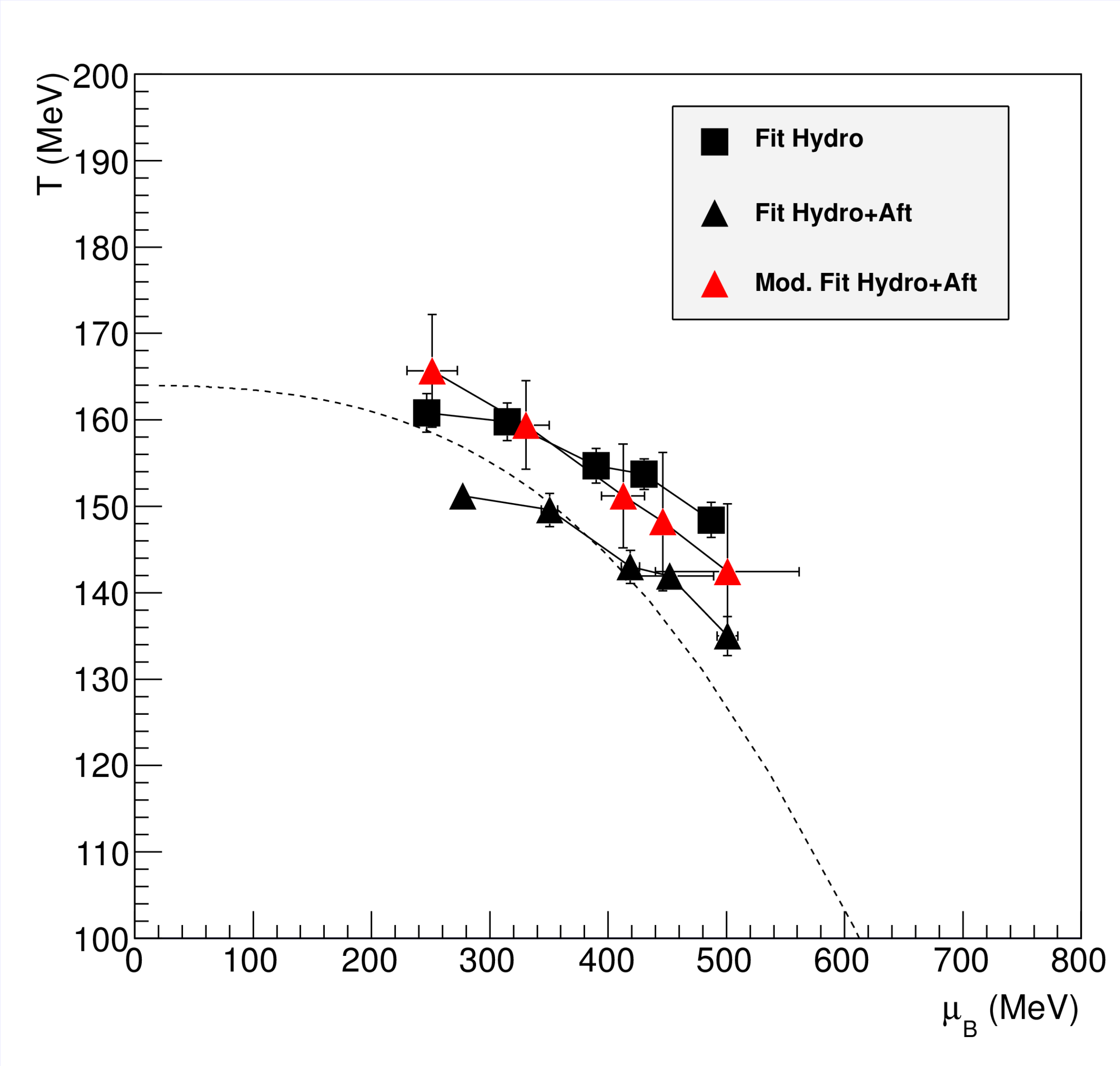


Second step: fitting to SHM (γ_s) - using exp. errors

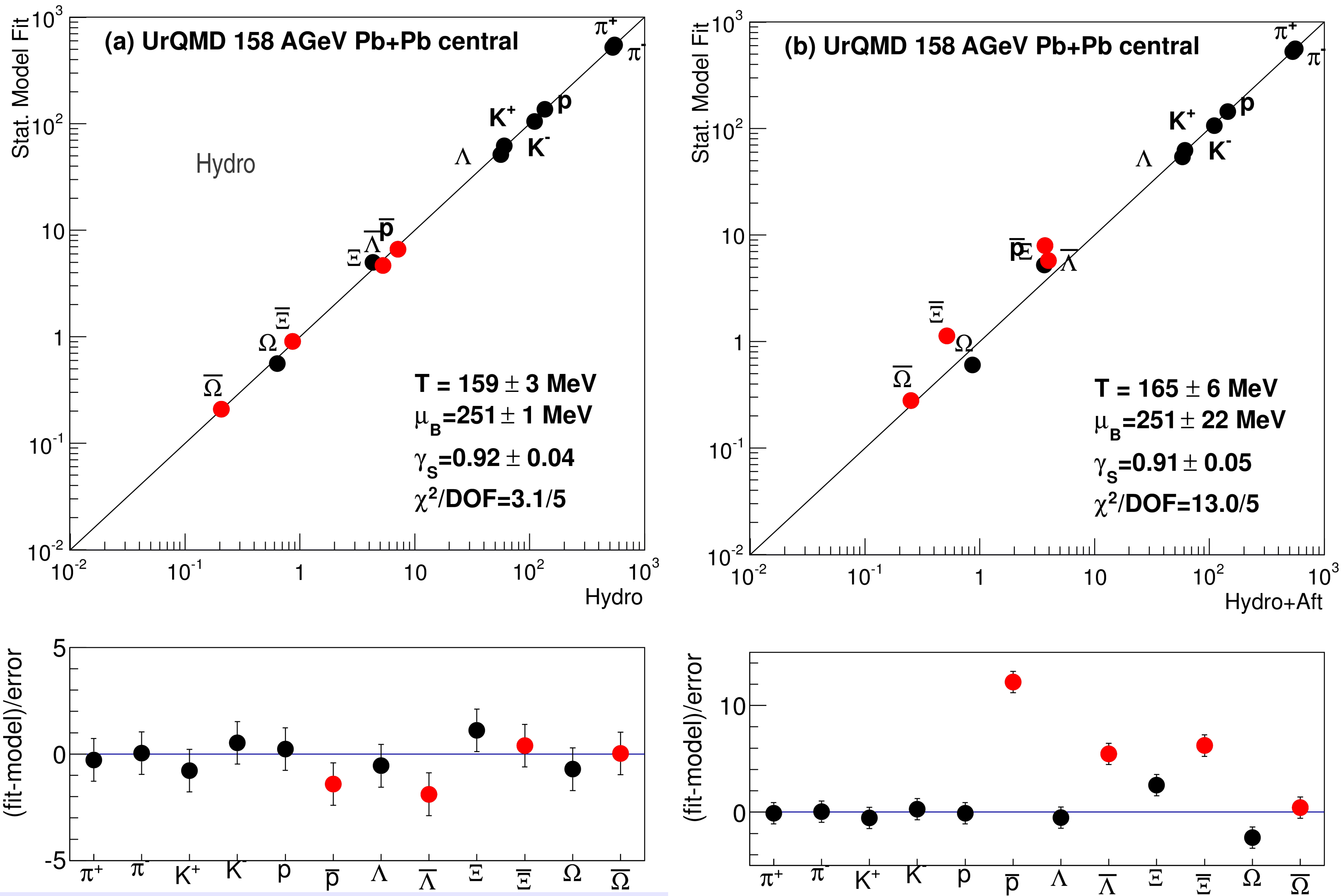


Major effects of including afterburning:

- Lowering the output c.f.o. T by ~ 10 MeV
- Sizeable worsening of fit quality

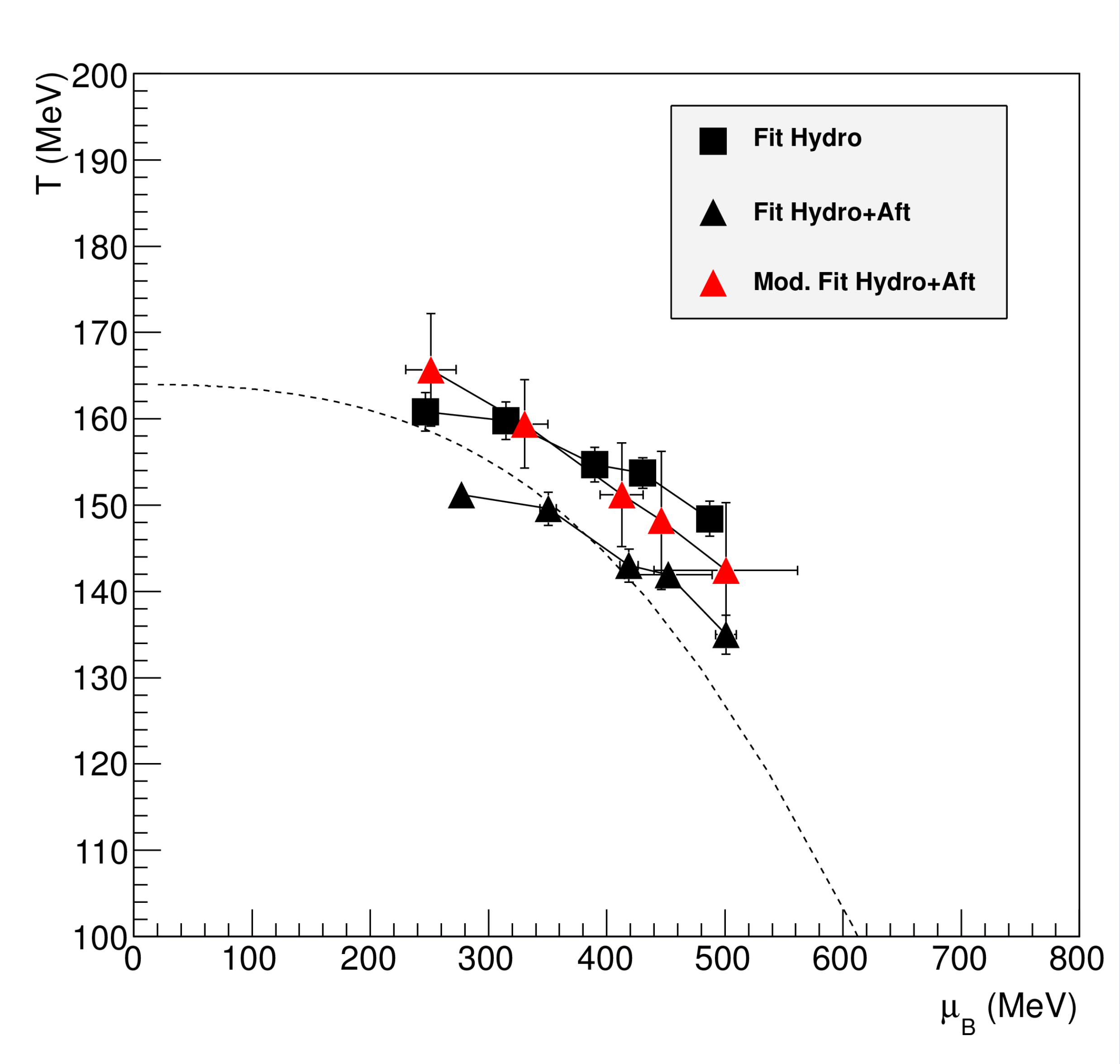


Third step: fitting to SHM (γ_S) removing antibaryons



Major effects of excluding antibaryons:

- Essential recovery of “original” freeze-out point
- Much better fit quality



If hydro+URQMD is a correct description of the physical process at SPS energy, fitting to the data <u>removing antibaryons</u> should give the hadronization point.

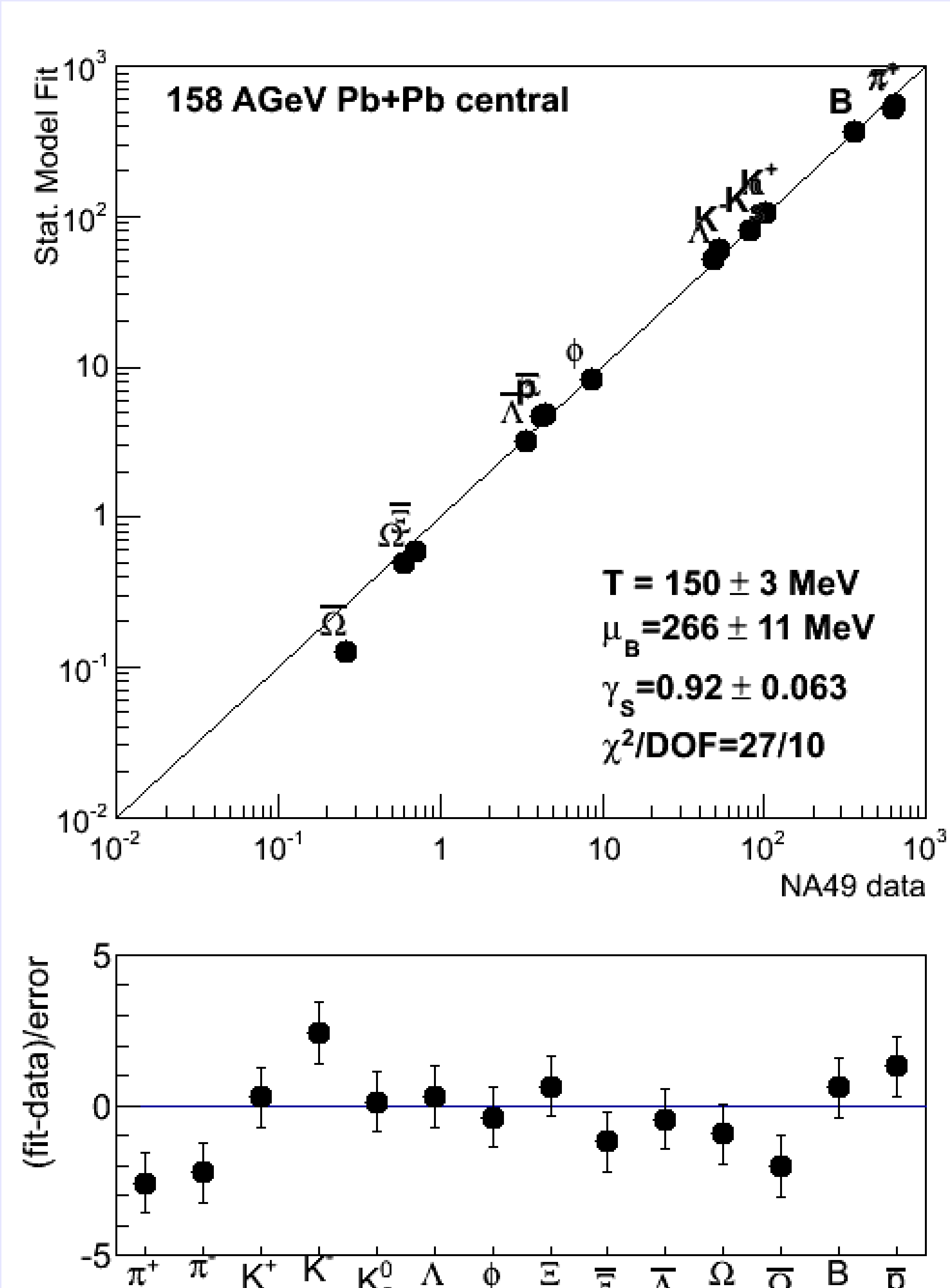
There are indications in this respect:

• the recent measurement of $\bar{p}$ by NA49 at 158A GeV is consistently lower than the predicted by SHM.

Predicted: 6.86 in F.B., J. Manninen and M. Gazdzicki, Phys. Rev. C 73 (2006) 044905
Measured: 4.23 ± 0.35

• the p ($\bar{p}$)/π yield at LHC is lower than predicted by the SHM by 40%
(see the recent analysis by Steinheimer, Aichelin, Bleicher ArXiv:1203.5302)

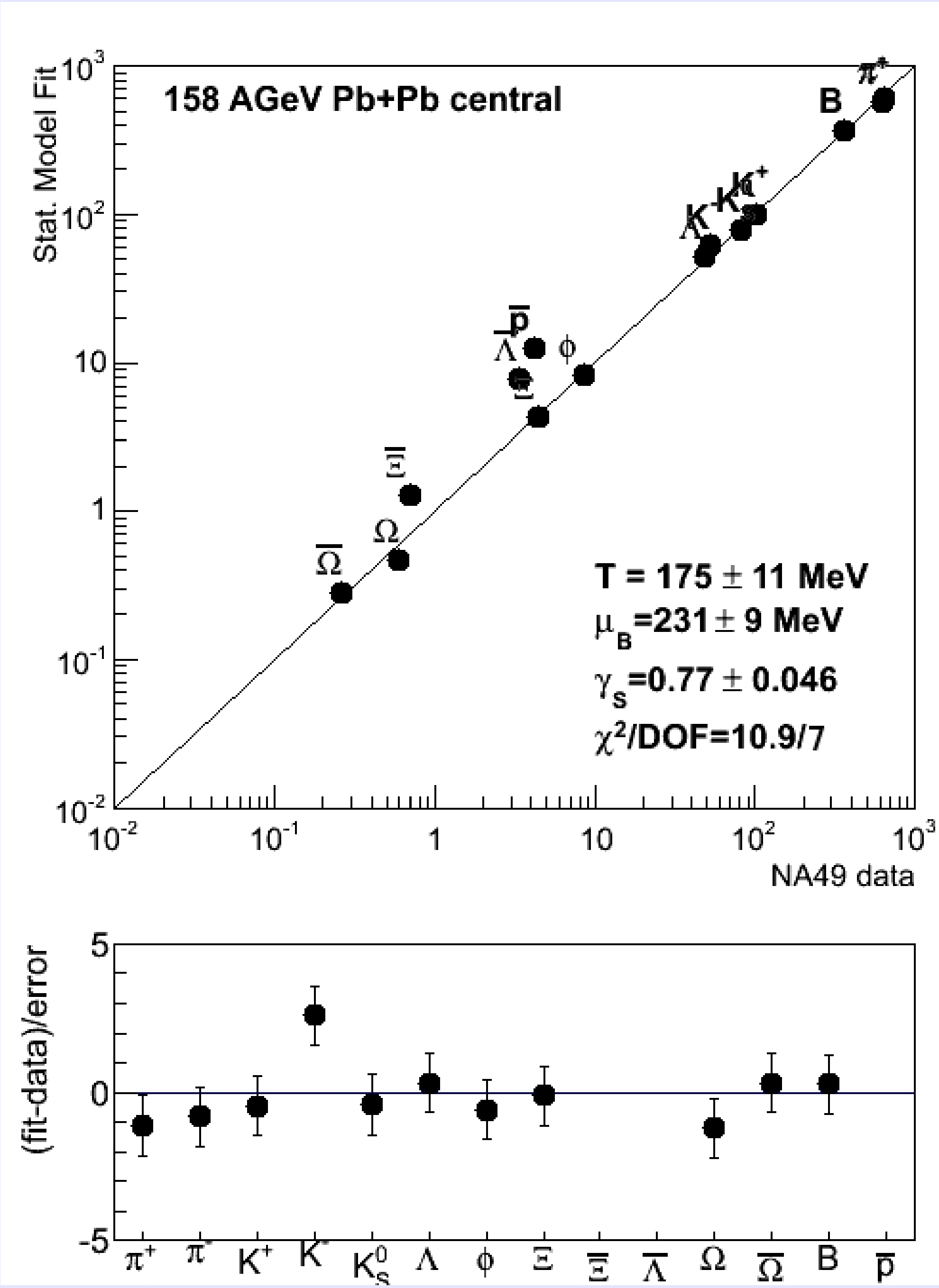
Usual fit to the most recent NA49 data set



Quite a low temperature and a χ^2 = 27/10

...seems to be in accordance with expectations from hydro+URQMD

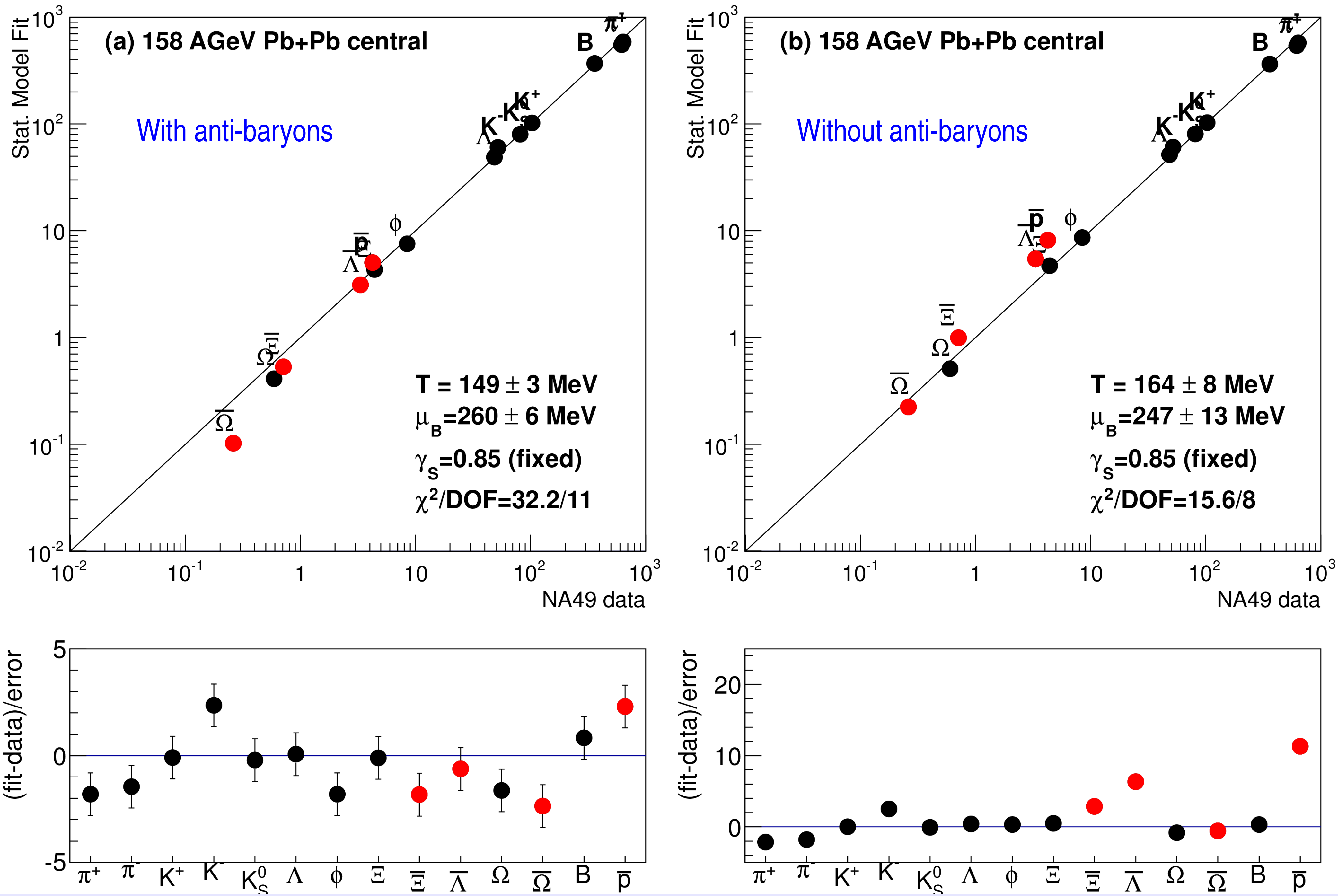
Fit to the most recent NA49 data set without antibaryons



Much better χ^2 = 11/7, with an unexpectedly large T though

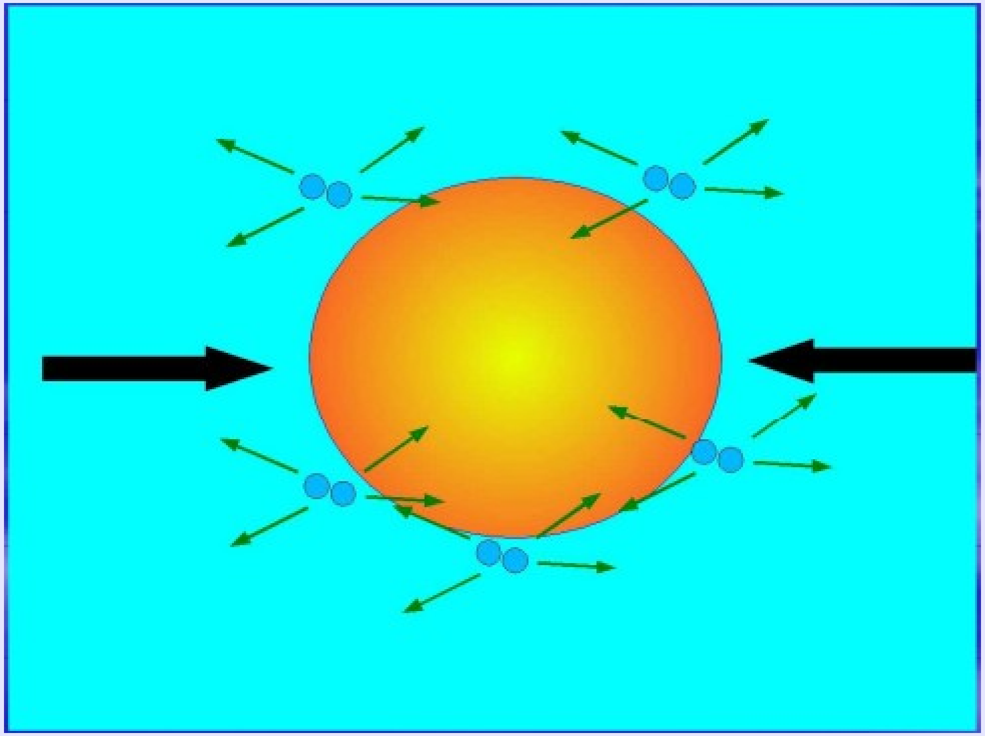
The problem is γ_s, which varies considerably from the all-inclusive fit.

Fixing γ_s and comparing...



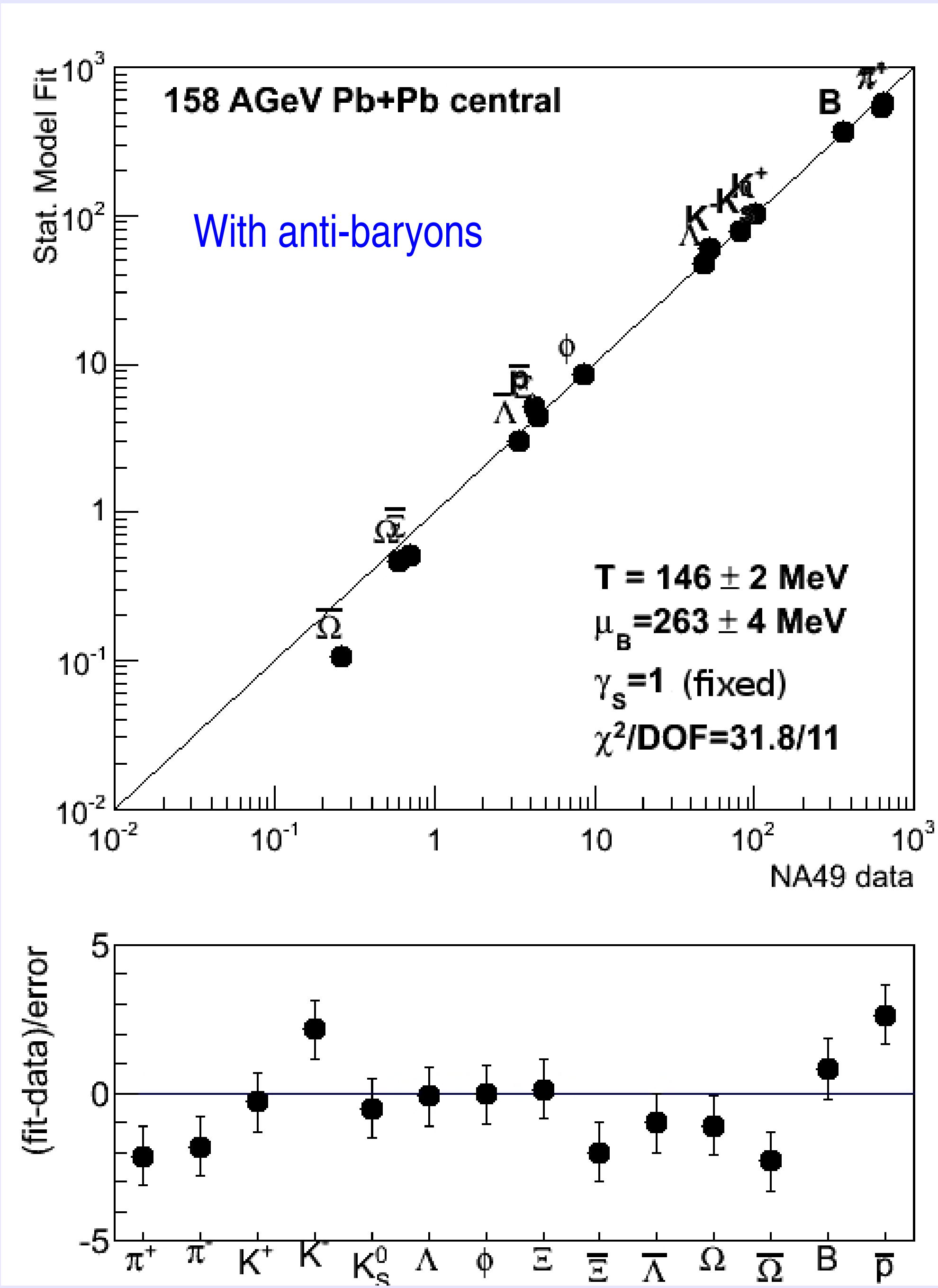
Core-corona model

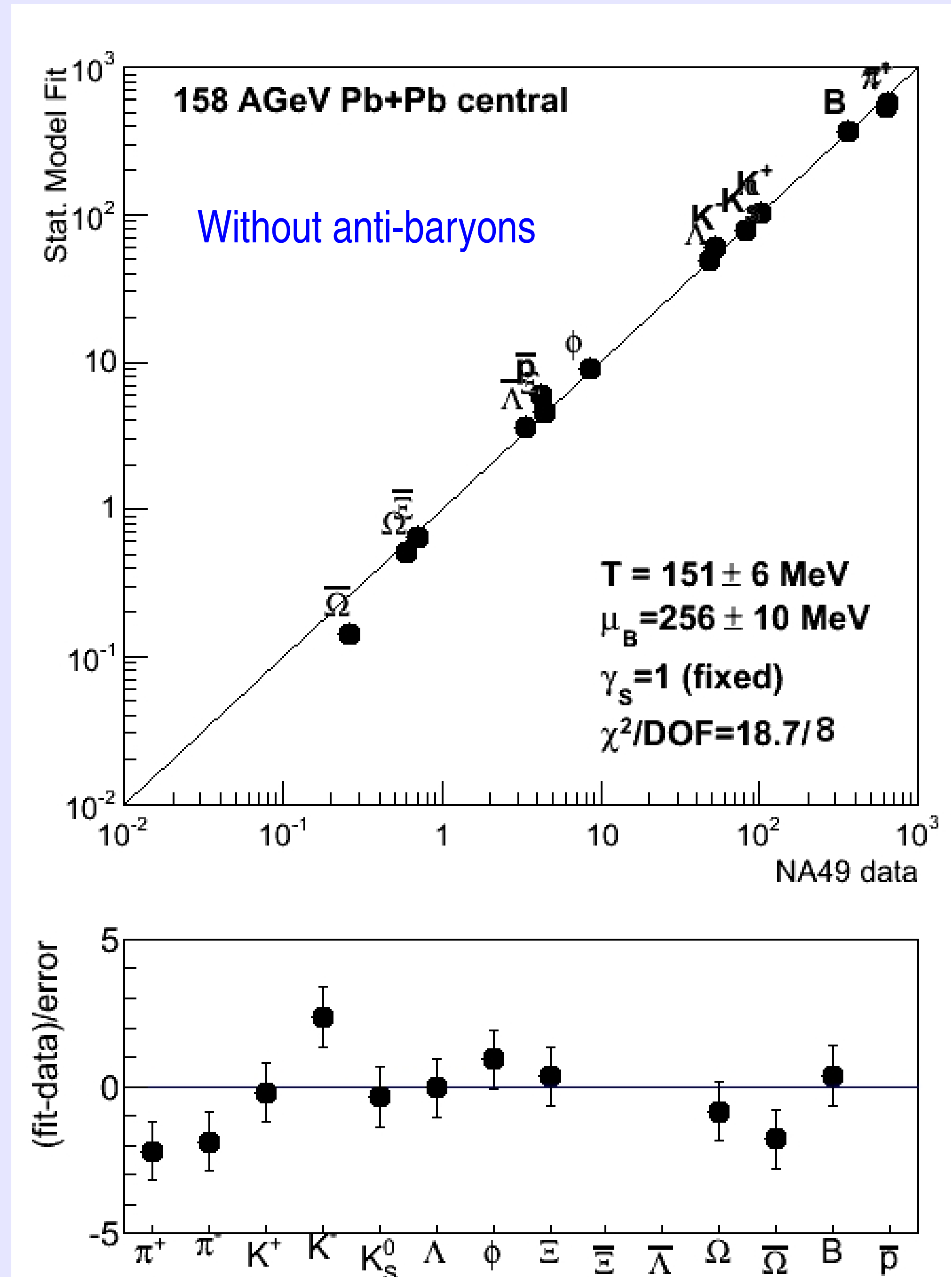
- γ_s =1 for the core
- γ_s < 1 in heavy ion collisions is the effect of peripheral single NN collisions, for which $\gamma_s \sim 0.5$
- Calculates N_c from Glauber



This approach reproduces very well the centrality dependence of strangeness enhancement (F.B., J. Manninen QM 2008 and J. Aichelin, K. Werner)

Core-corona: replace γ_s with Nc (fixed from Glauber model)





Conclusions and outlook

- At top SPS data, in central Pb-Pb collisions, there seems to be some distance between hadronization and chemical freeze-out. The temperature shift is 5-15 MeV, depending on the fitting model.

- There should be some (slight) dependence of C.F.O. on centrality: repeat the analysis with NA49 data taken in different centrality bins.

- This analysis is to be extended to higher energy (RHIC and LHC) which is especially interesting in view of the p/pion low ratio.