The statistical model in Pb-Pb collisions at the LHC

- Introductory remarks – is quark matter at LHC in equilibrium?
- Energy dependence of hadron production and statistical model
- Is there a proton anomaly at LHC energy?

FIAS-Frankfurt

work based on collaboration with
A. Andronic, K. Redlich, and J. Stachel

9th RANP conference
Rio de Janeiro
Brasil, Sep. 23-27, 2013

Peter Braun-Munzinger

Equilibration at the phase boundary

- Statistical model analysis of (u,d,s) hadron production: an important test of equilibration of quark matter near the phase boundary, **no equilibrium → no QGP matter**

- No (strangeness) equilibration in hadronic phase

- Present understanding: multi-hadron collisions near phase boundary bring hadrons close to equilibrium – supported by success of statistical model analysis

pbm, Stachel, Wetterich,
Phys.Lett. B596 (2004) 61-69

- This implies little energy dependence above RHIC energy

- Analysis of hadron production → determination of T_c

Is this picture also supported by LHC data?

The QCD phase diagram and chemical freeze-out

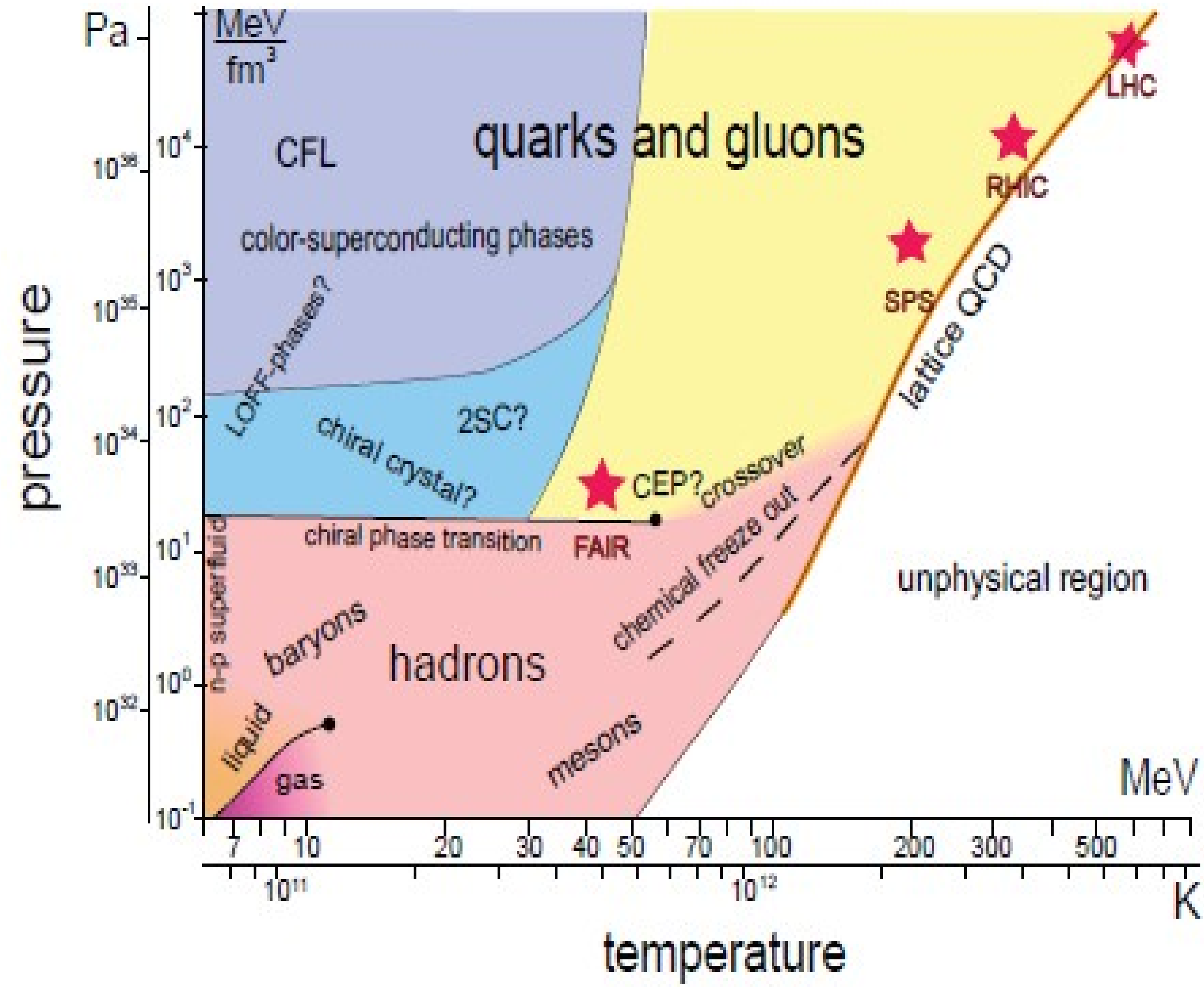
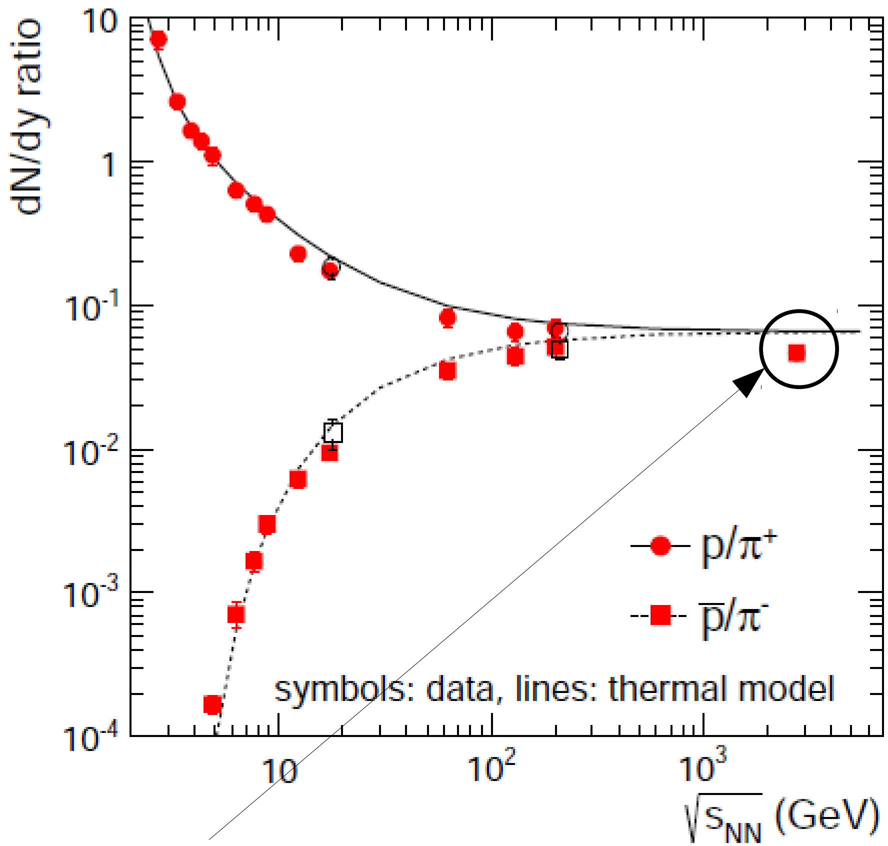
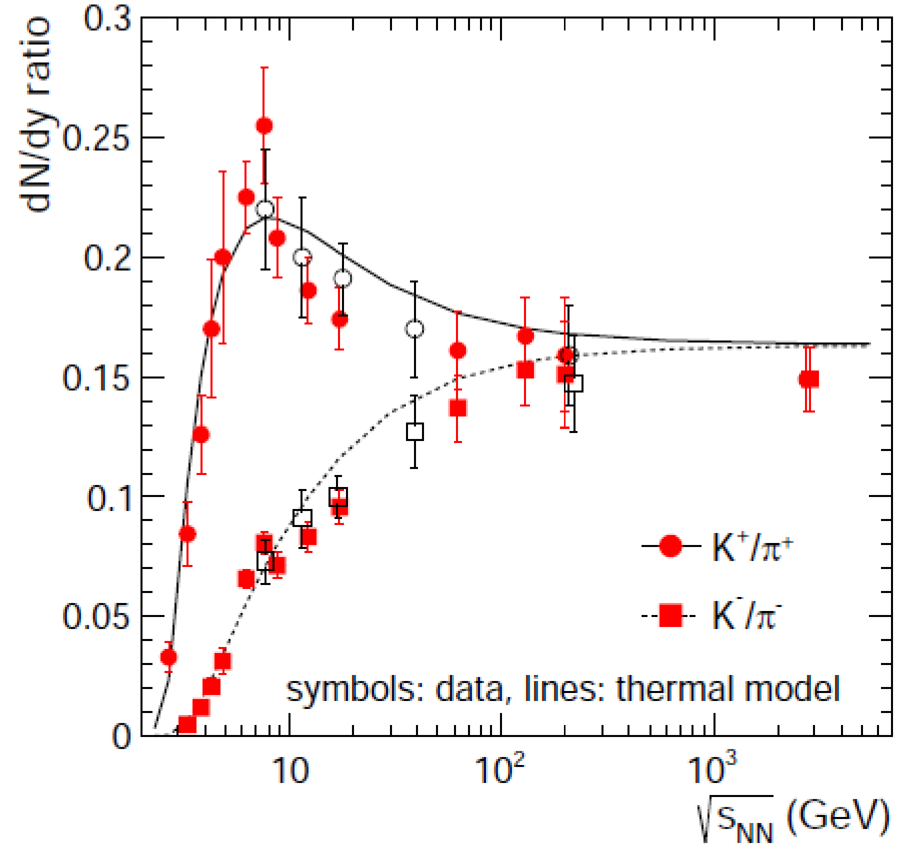


fig. from Wambach, Heckmann, Buballa, arXiv:1111.5475

Summary of pre-LHC era

overall systematics, including ALICE data, on proton/pion and kaon/pion ratios





proton anomaly?

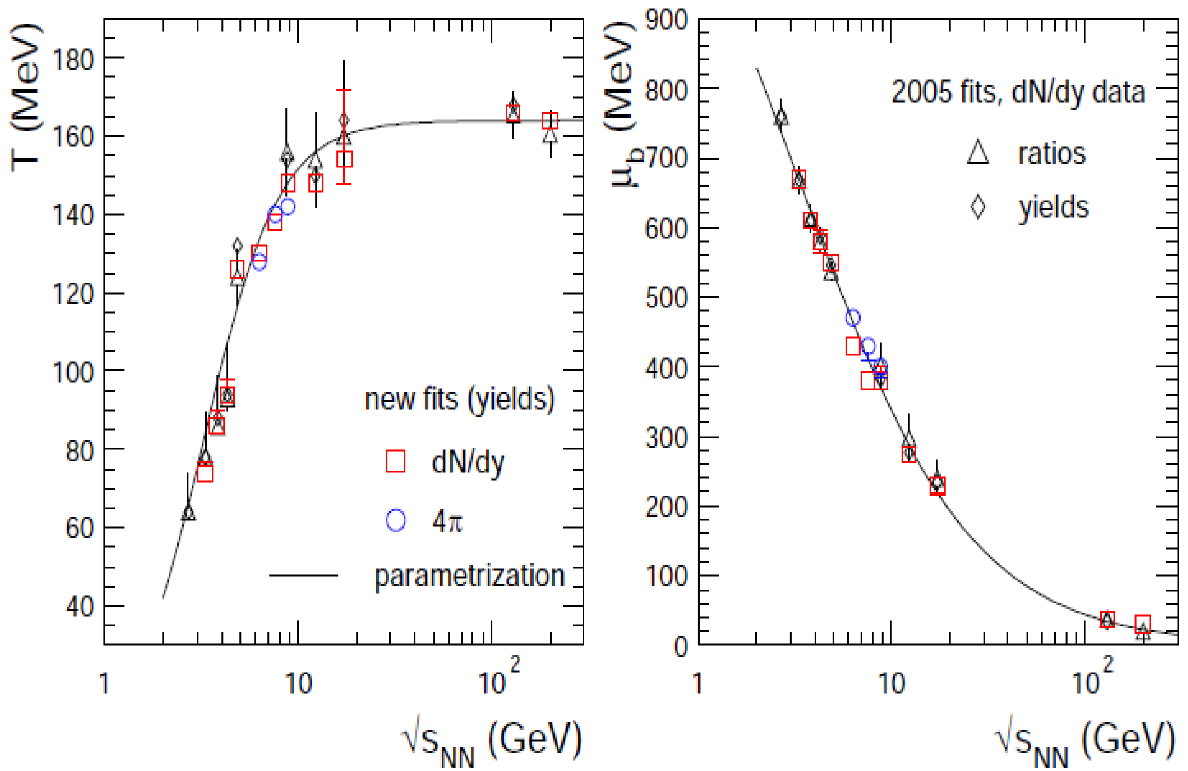
Parameterization of all freeze-out points before LHC data

note: establishment of limiting temperature

T_{lim} = 160 +/- 4 MeV

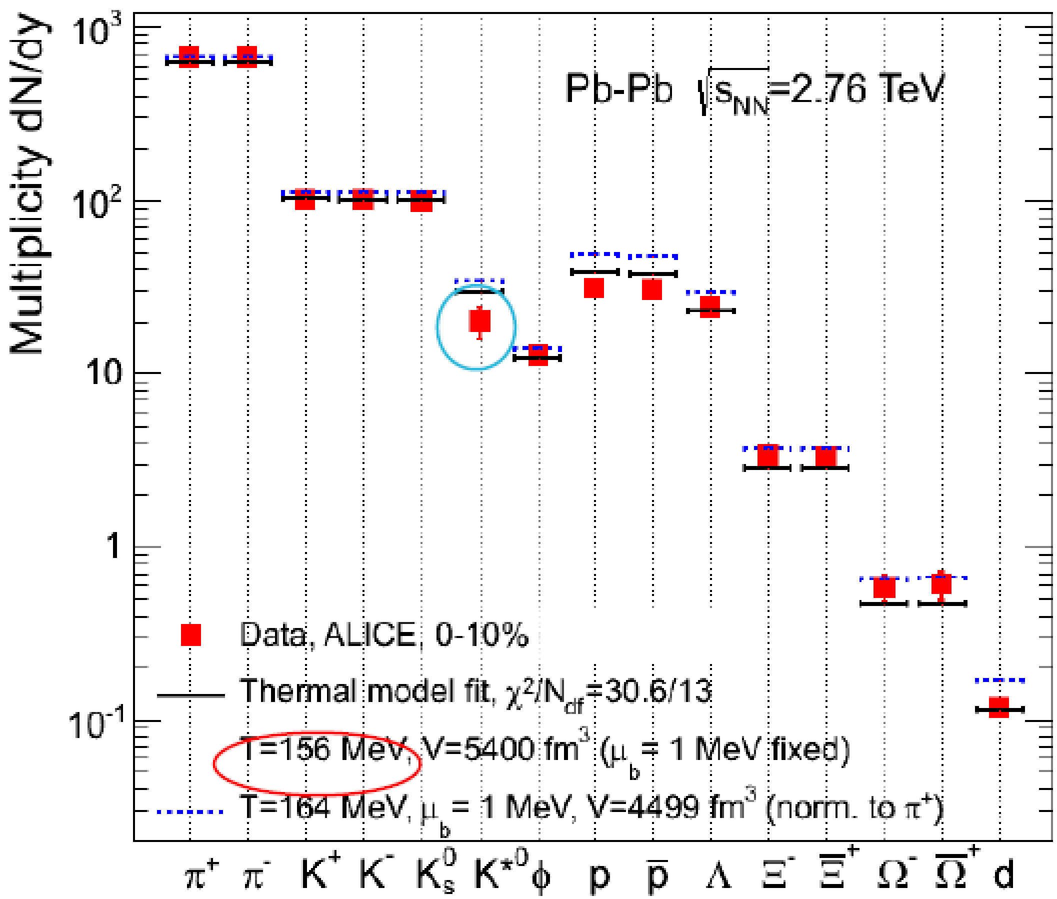
get T and μ_B for all energies

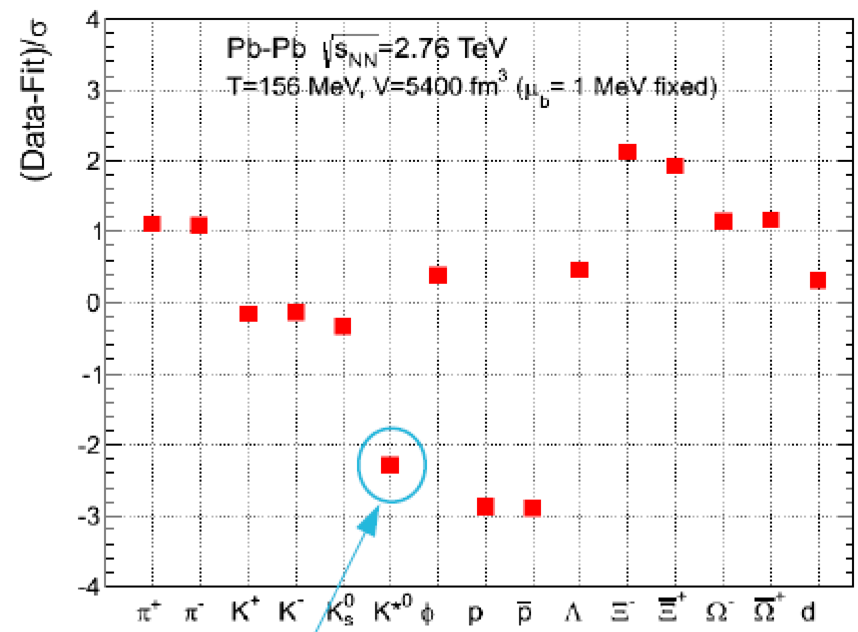
for LHC predictions we picked T = 164 MeV



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

New fit of Alice data including hyperons and light nuclei





strongly decaying resonance

protons low by 2.9 σ

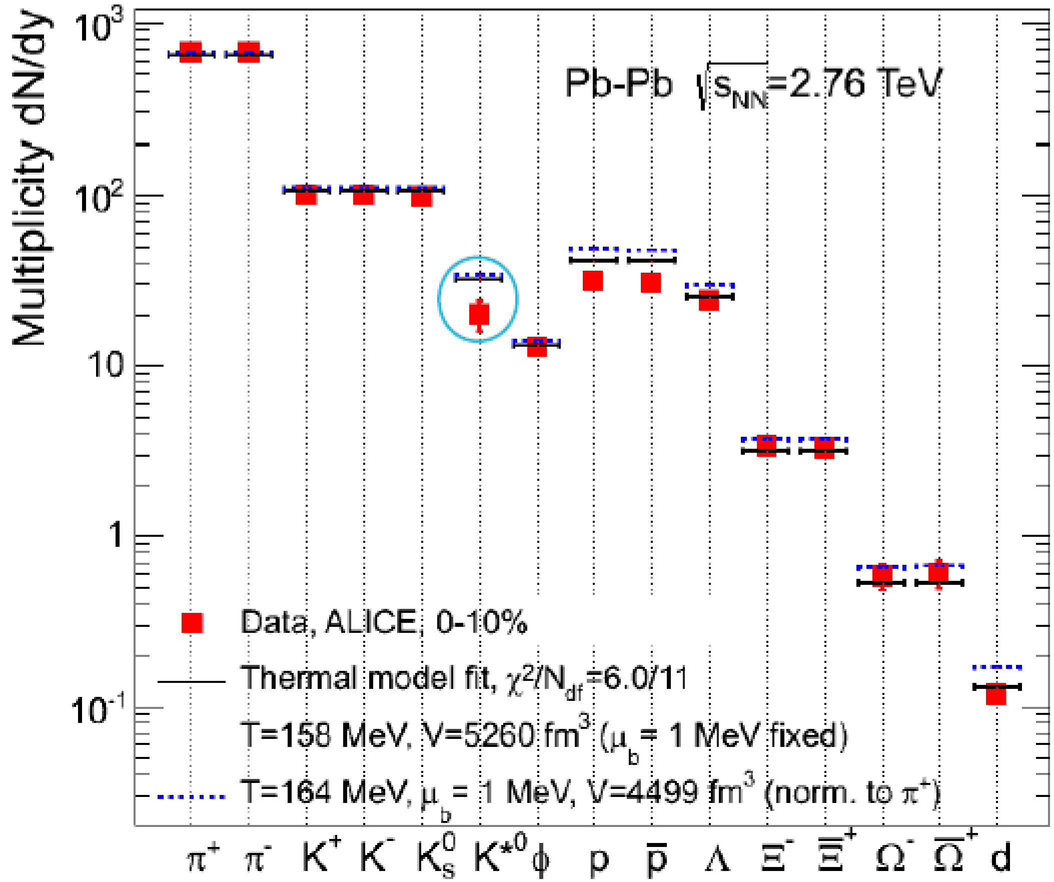
as compared to 2012: more and final data

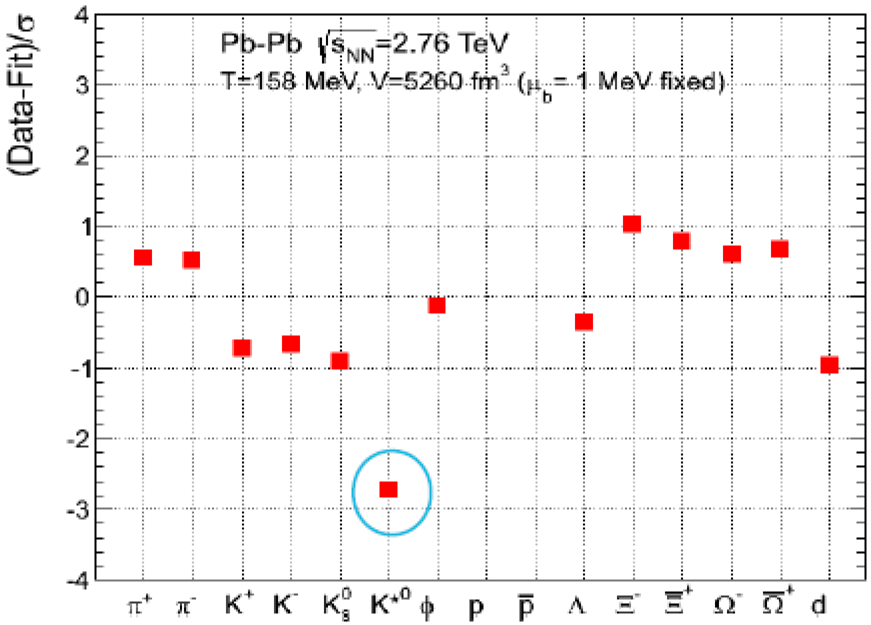
T went from 152 to 156 MeV

red. χ^2 went from 4 to 2.35

T = 156 MeV produces quite a good fit to all data!

fit to data excluding protons





excellent fit, T = 158 MeV

where are we?

since QM2012, discrepancy between protons and thermal fit went from 7 sigma to 2.9 sigma

T went from 152 to 156 MeV

fit without protons yields slighty higher T = 158 MeV, driven by hyperons

important note: corrections for weak decays

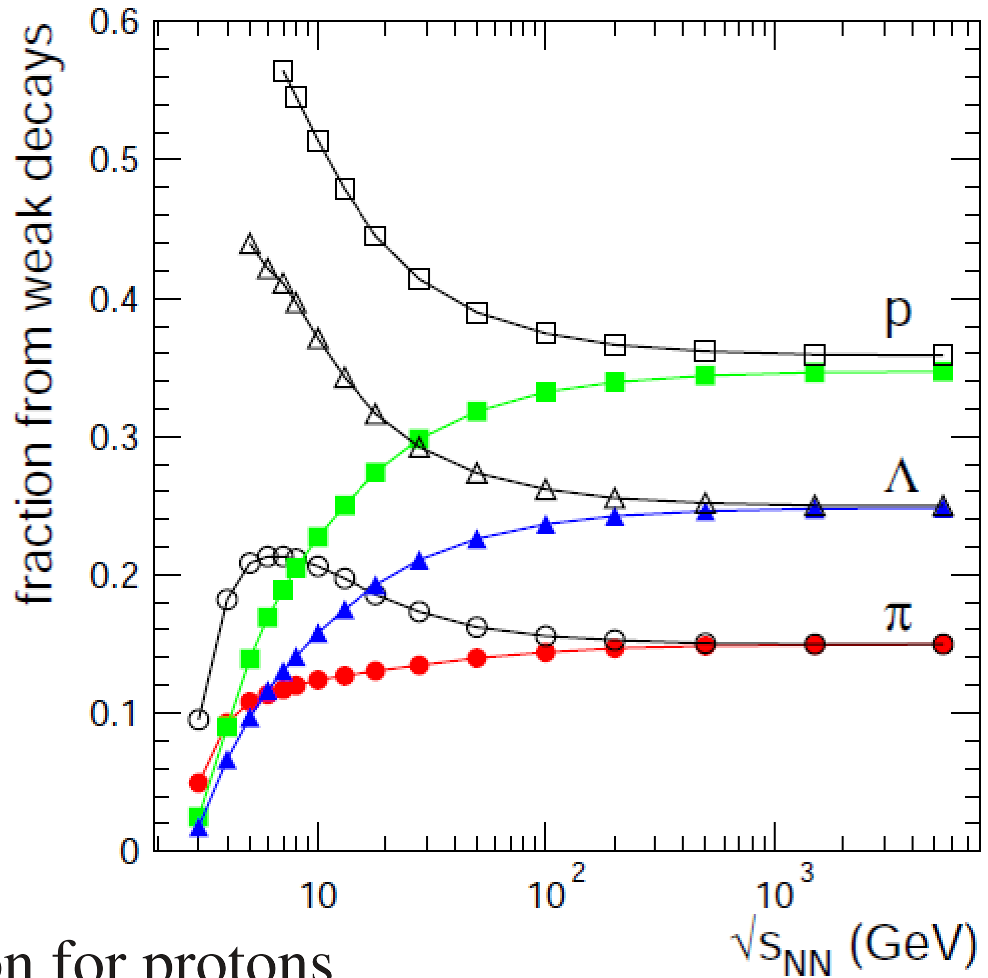
All ALICE data do not contain hadrons from weak decays of hyperons and strange mesons – correction done in hardware via ITS inner tracker

The RHIC data contain varying degrees of such weak decay hadrons. This was on average corrected for in previous analyses.

in light of high precision LHC data the corrections done at RHIC may need to be revisited.

treatment of weak decays

fraction of yield from weak decays



biggest correction for protons
done in hardware (vertex cut) at ALICE
software corrections at all lower energies

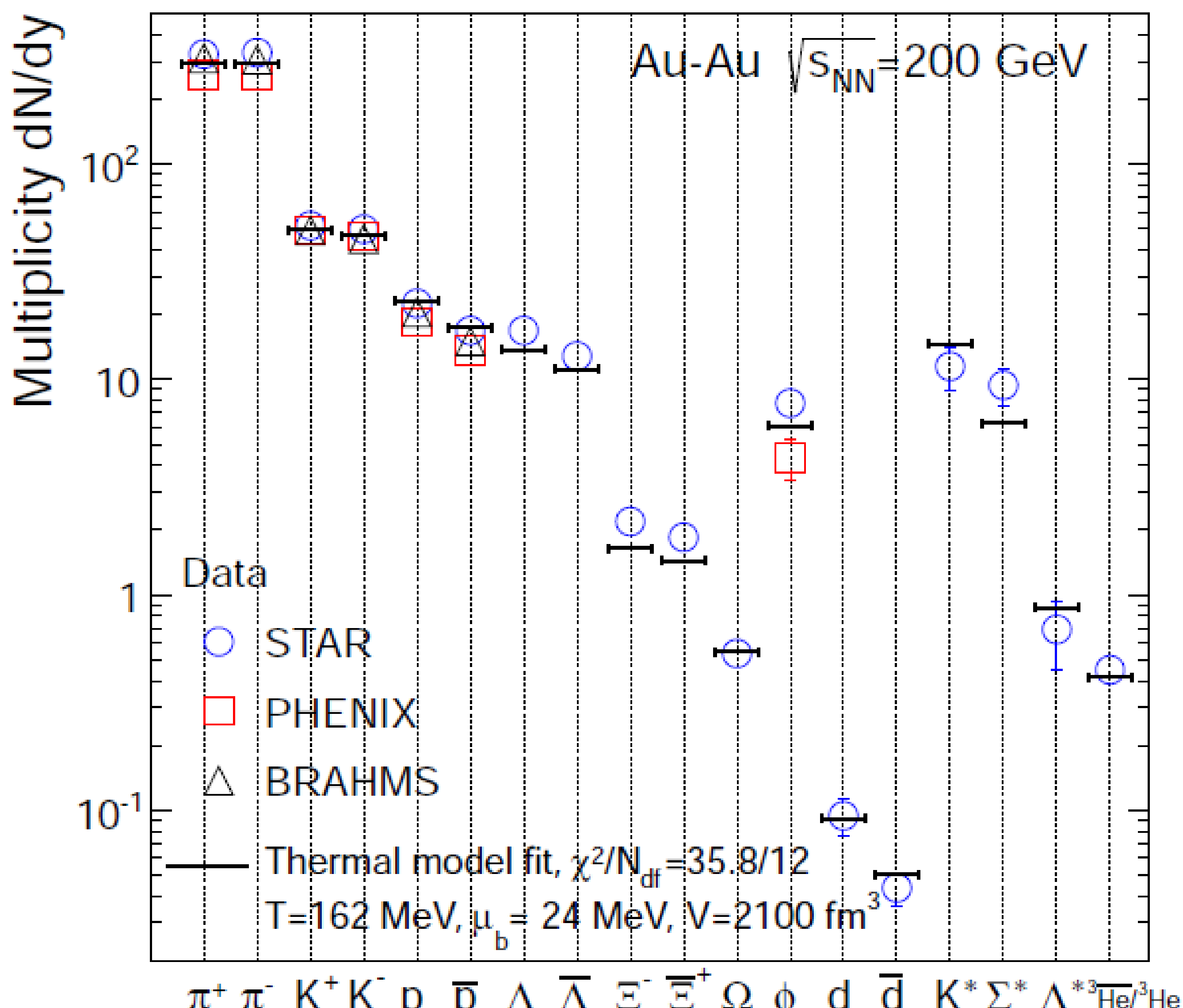
Re-evaluation of fits at RHIC energies – special emphasis on corrections for weak decays

Note: corrections for protons and pions from weak decays of hyperons depend in detail on experimental conditions

RHIC hadron data all measured without application of Si vertex detectors

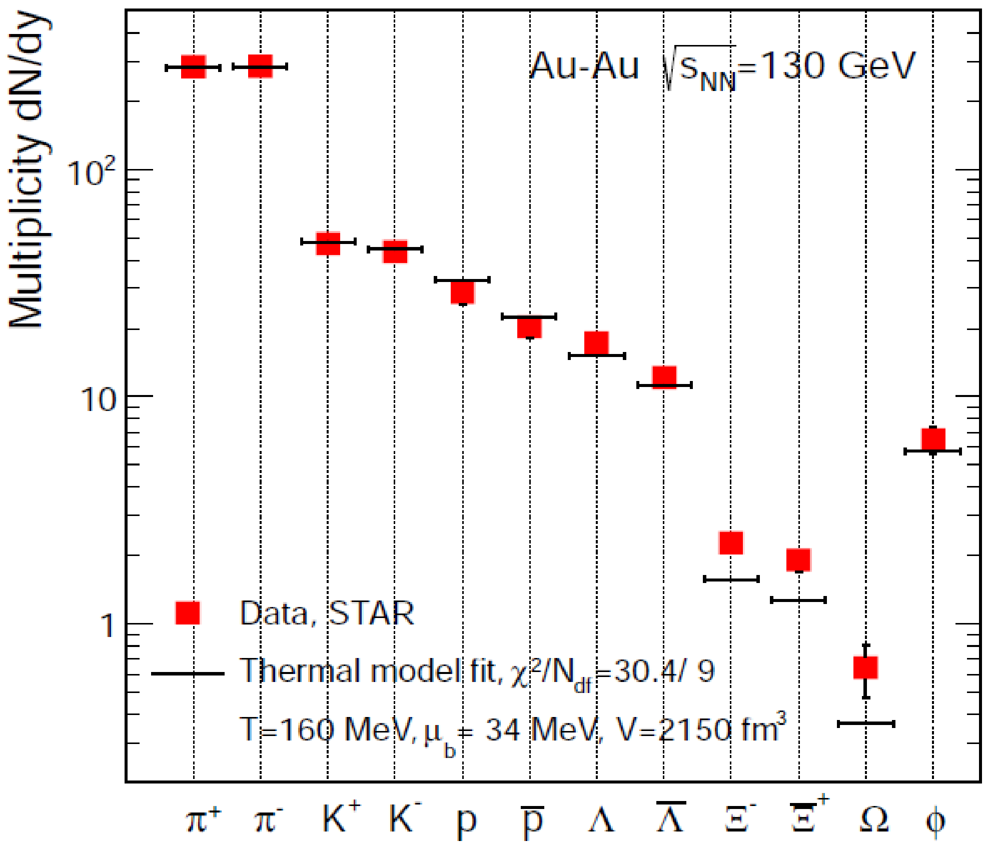
In the following, corrections were applied as specified by the different RHIC experiments

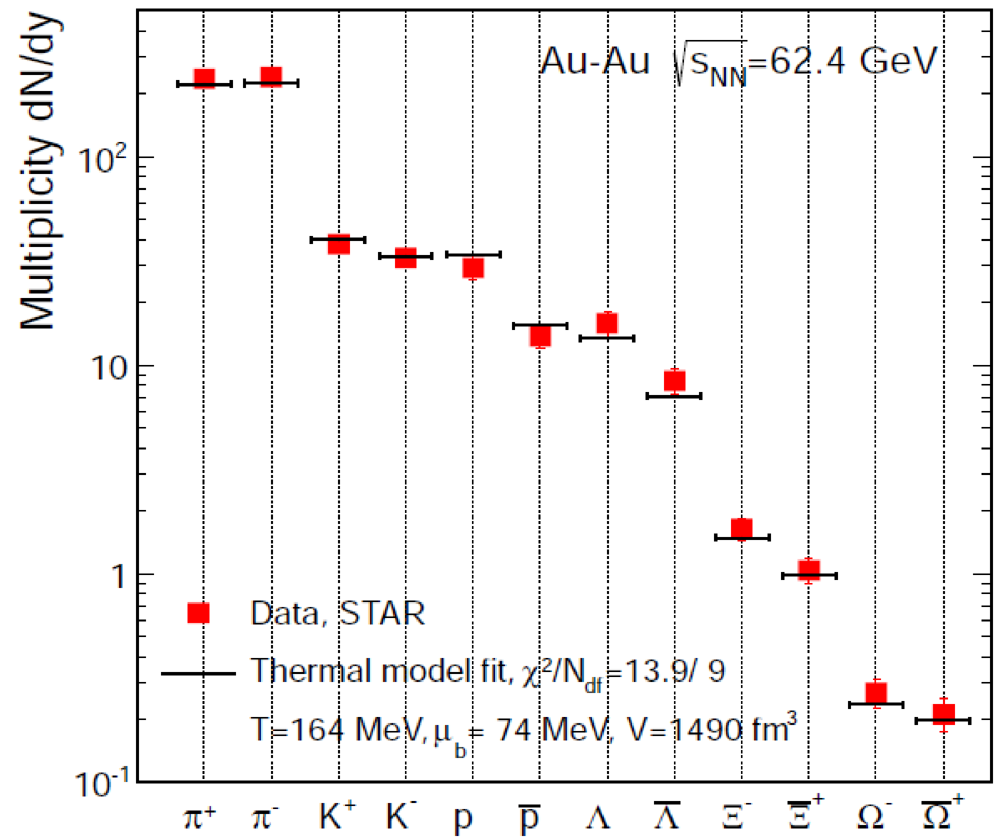
Au+Au central at 200 GeV, all experiments combined



T = 162 MeV

Example: RHIC lower energies, STAR data alone





good fits, T = 160 – 164 MeV

could it be weak decays from charm?

weak decays from charmed hadrons are included in the ALICE data sample

at LHC energy, cross sections for charm hadrons is increased by more than an order of magnitude compared to RHC

first results including charm and beauty hadrons indicate changes of less than 3%, mostly for kaons

not likely an explanation

could it be proton annihilation in the hadronic phase?

F. Becattini et al., Phys. Rev. C85 (2012) 044921 and arXiv: 1212.2431

- need to incorporate detailed balance, 5pi → p p_bar
  not included in current Monte Carlo codes (RQMD)

- taking detailed balance into account reduces effect strongly,
see Rapp and Shuryak 1998

recent reanalysis: effect reduced by about factor of 2

Pan and Pratt, PRL 110 (2013) 042501

- agreement with hyperon data would imply strongly reduced hyperon annihilation cross section with anti-baryons → no evidence for that

the 'proton anomaly' and production of light nuclei

can the measurement of d, t, 3He and 4He settle the issue?
what about hypertriton?

important to realize: production yield of deuterons is fixed at $T = T_{chem} = 158$ MeV even if $E_B(d) = 2.3$ MeV!

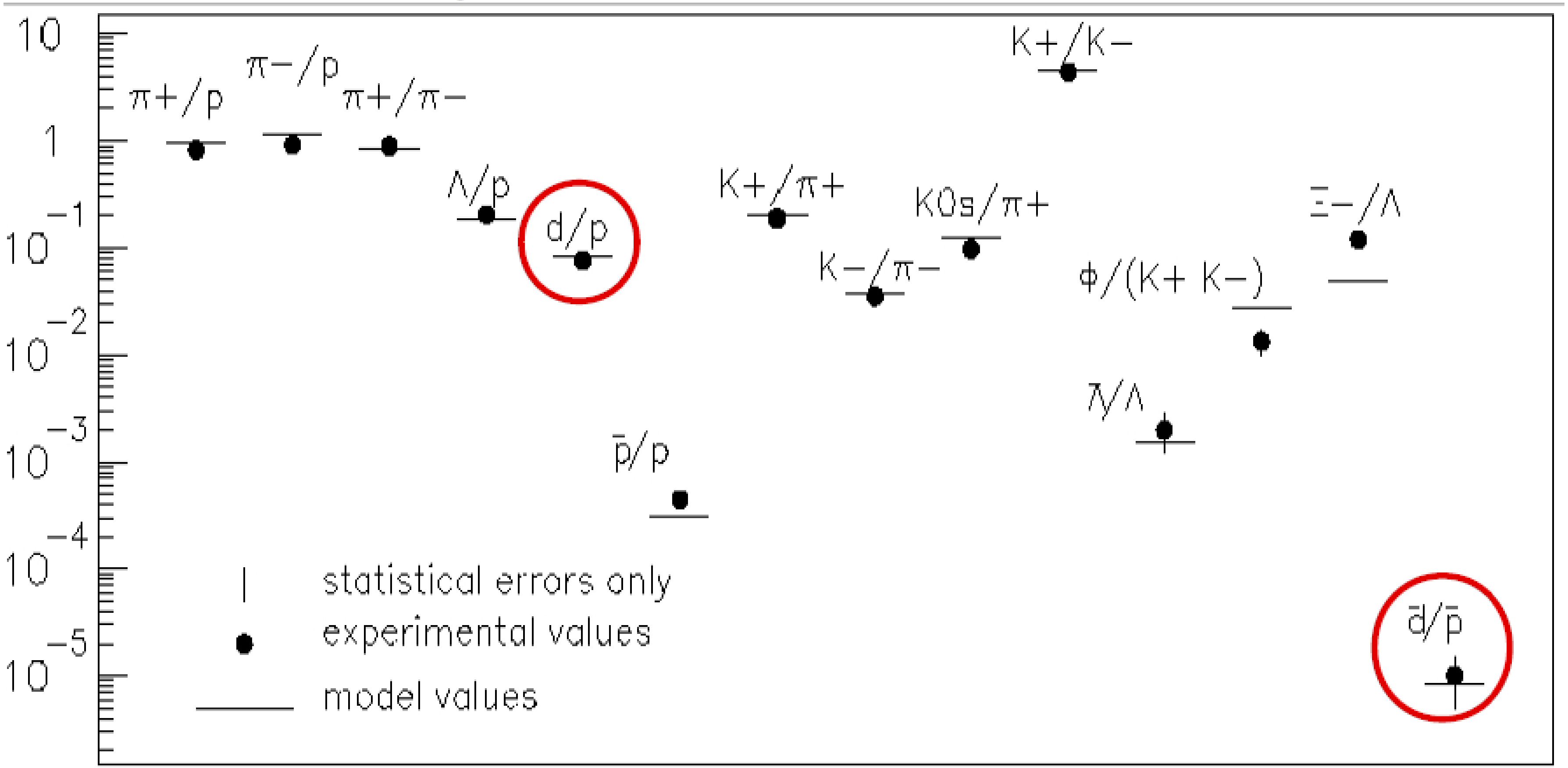
entropy/baryon is proportional to $-\ln(d/p)$ and is conserved after T_{chem}

good agreement with LHC d yield implies: there is no shortage of protons and neutrons at chemical freeze-out, inconsistent with annihilation scenario

deuterons and anti-deuterons also well described at AGS energy

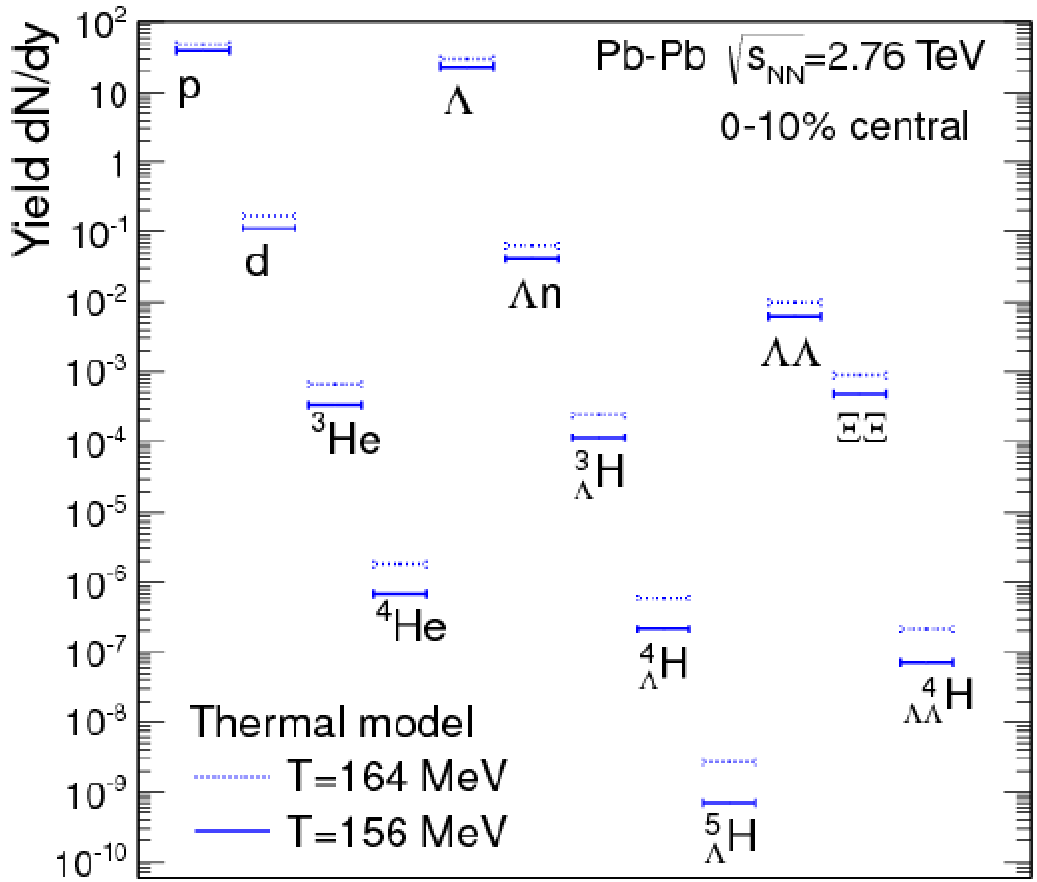
14.6 A GeV/c central Si + Au collisions and GC statistical model

P. Braun-Munzinger, J. Stachel, J.P. Wessels, N. Xu, PLB 1994



dynamic range: 9 orders of magnitude! No deviation

Predictions using the thermal model for light nuclei, hypernuclei, and exotica



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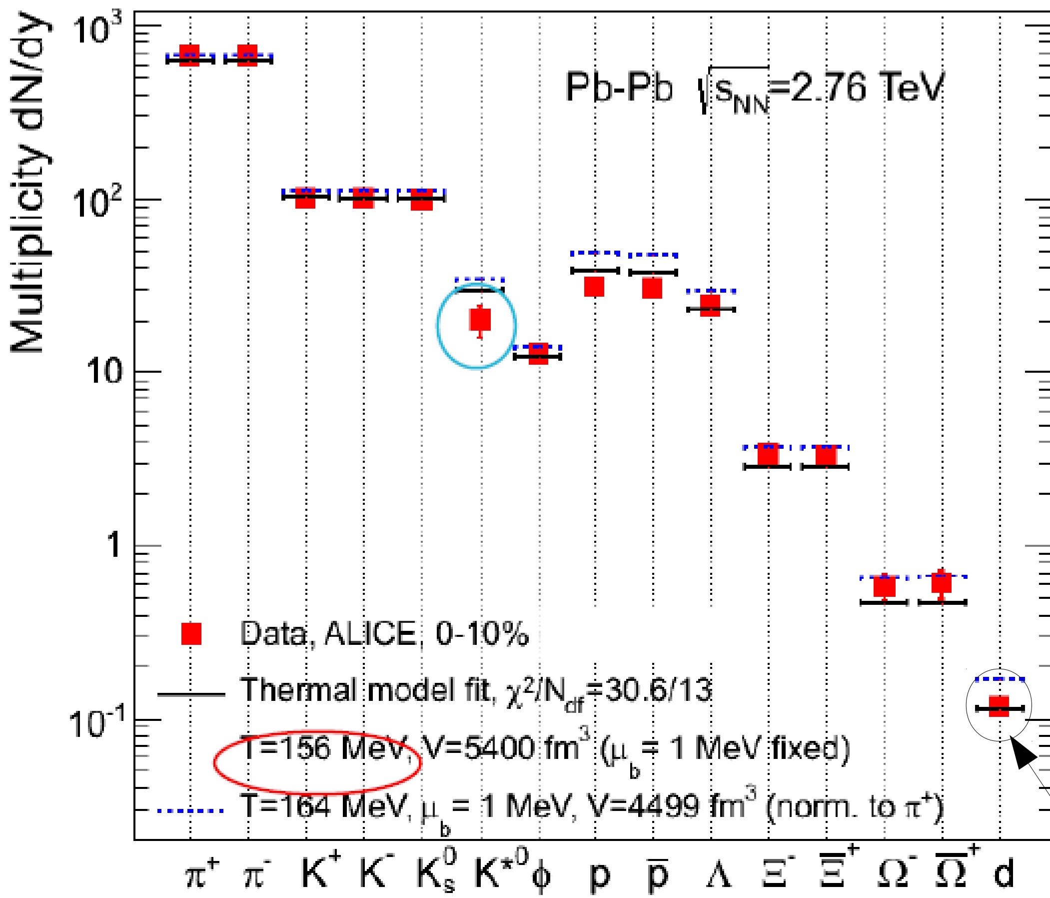

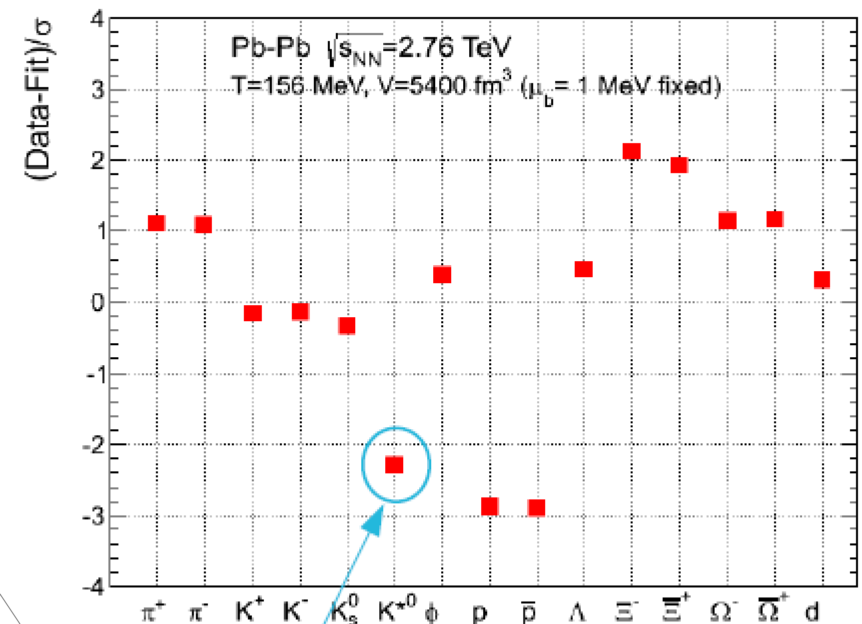

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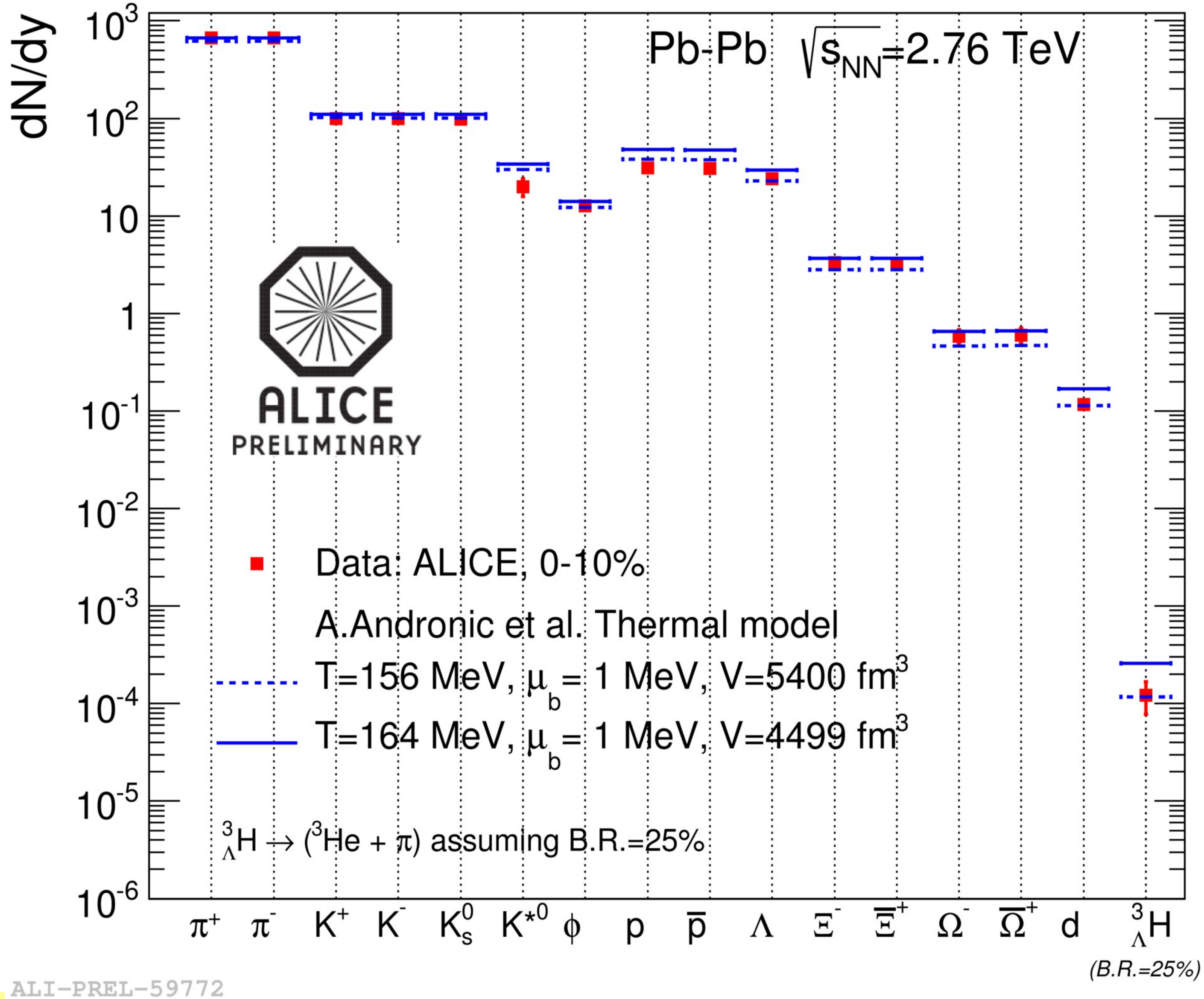
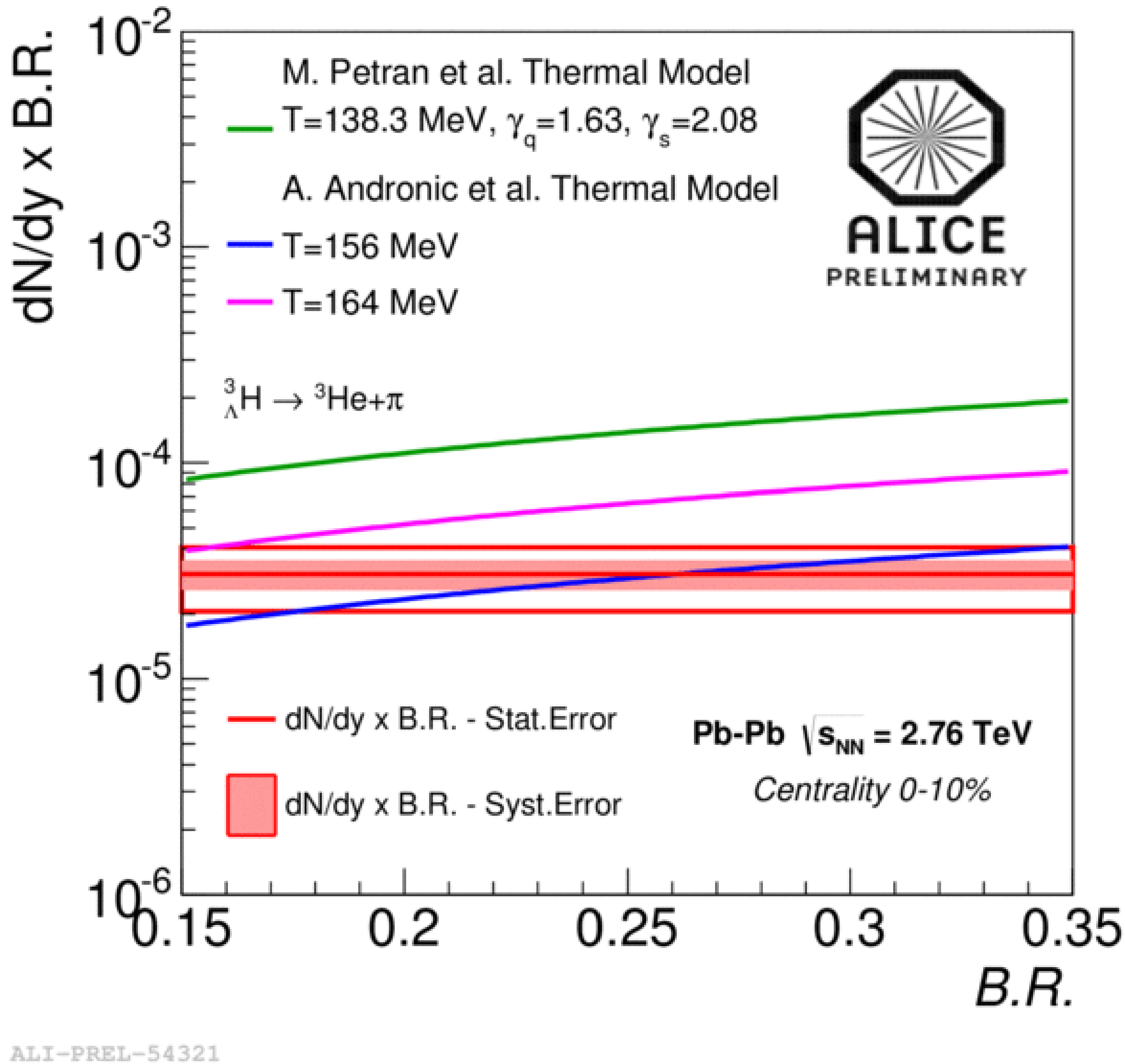


T = 156 MeV also works for hypertriton

good agreement over more than 6 orders of magnitude

Hypertriton yield x branching ratio and the thermal model



analysis spearheaded by Ramona Lea, ALICE

T = 156 MeV provides very good description

Note: binding energy of hypertriton is 100 keV!!
Most likely B.R. = 0.25 (also used by STAR)

summary of this part:

annihilation scenario unlikely in view of d and hypertriton data

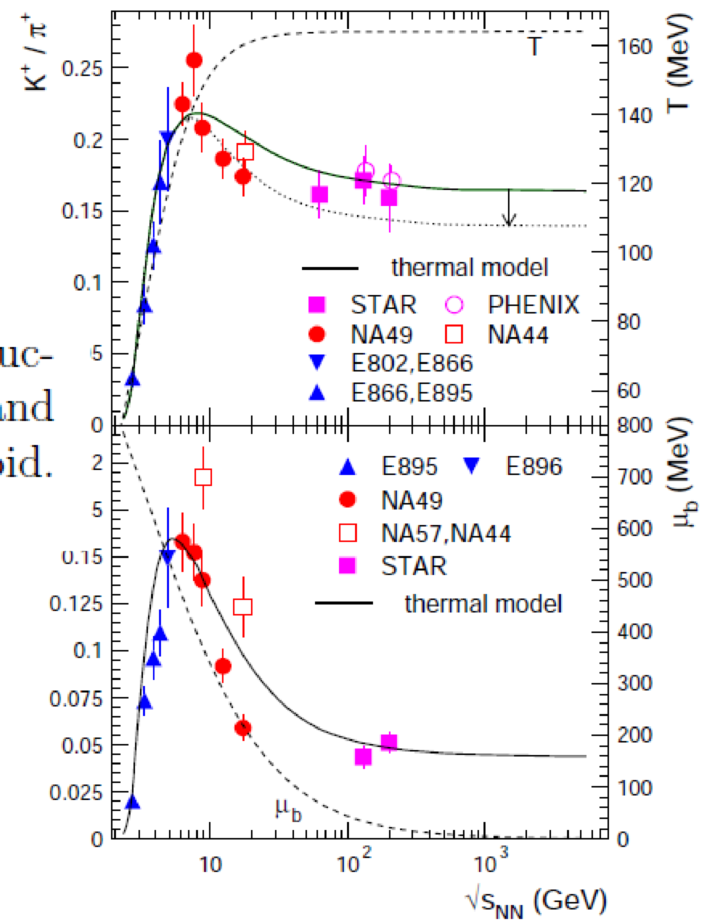
could it be incomplete hadron resonance spectrum?

Note: because of baryon conservation, adding more baryon resonances will decrease in the model the p/pi ratio

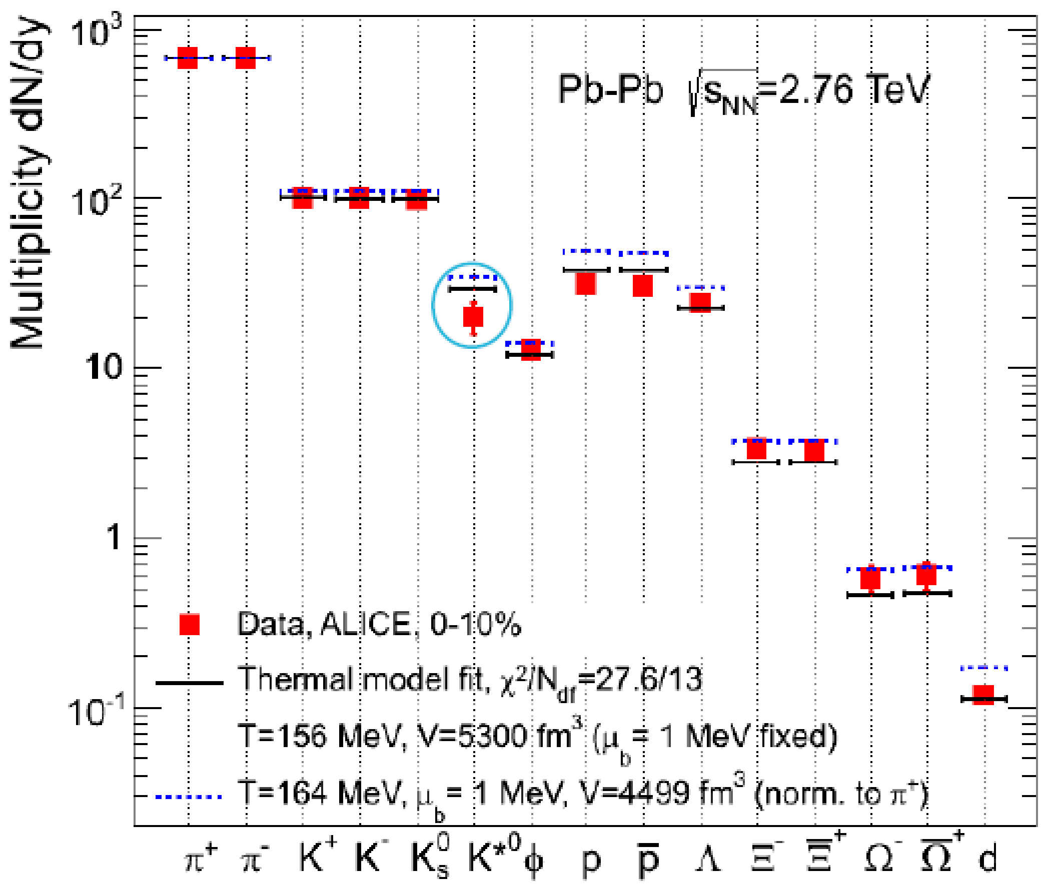
An N* will decay dominantly into 1 N + a number (depending on the N* mass) of pions

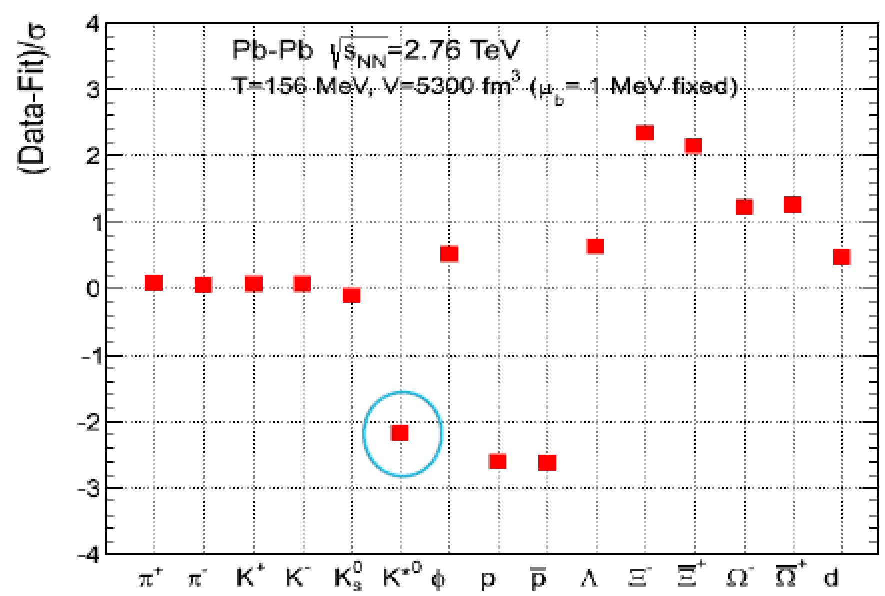
Same effect seen in
K/pi ratio because of strangeness conservation

A. Andronic, P. Braun-Munzinger, J. Stachel, Thermal hadron production in relativistic nuclear collisions: the sigma meson, the horn, and the QCD phase transition, Phys. Lett. **B673** (2009) 142, erratum ibid. **B678** (2009) 516, arXiv:0812.1186.



a little test: increase number of pions by 10%





fit is improved, but only moderately

will continue with further studies in this direction

summary

the Pb-Pb central collision hadron yields from run1 are well described by assuming equilibrated matter at T = 156 MeV and mu_b < 1 MeV

the original > 7 sigma proton anomaly is now 2.9 sigma

reproduction of the deuteron yield does not lend support to annihilation scenarios after chemical freeze-out

implementation of additional baryon resonances will be the next step

overall the LHC data provide strong support for chemical freeze-out driven by the (cross over) phase transition