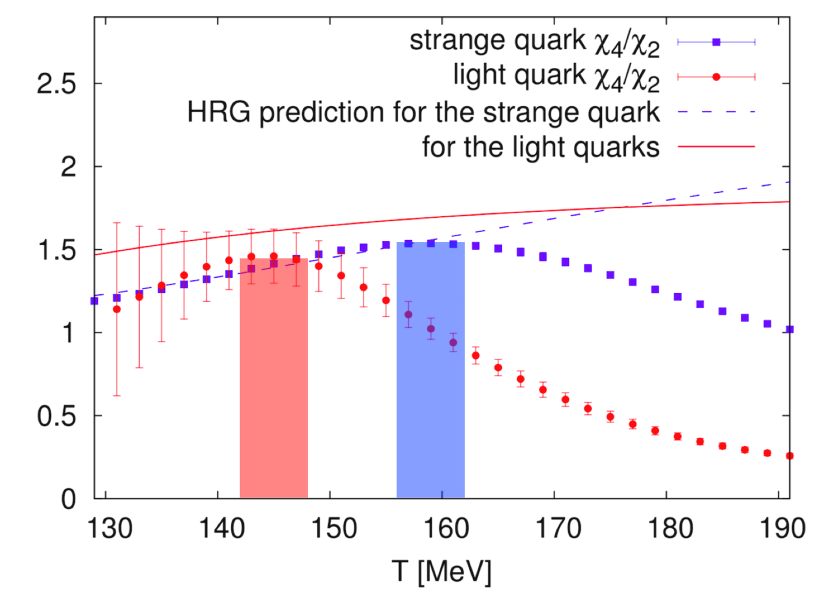
System Size and Flavour Dependence of Chemical Freeze-out in Relativistic Heavy Ion Collisions from RHIC-BES to LHC Energies

René Bellwied, Fernando Antonio Flor, Gabrielle Olinger

UNIVERSITY of HOUSTON | PHYSICS

I. Motivation

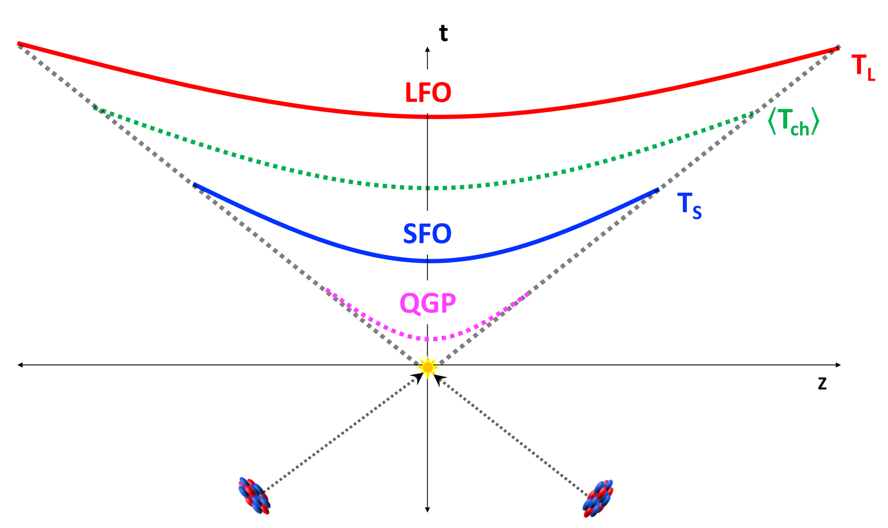


Continuum Extrapolated Lattice QCD results for χ_4/χ_2 for light and strange quarks depict different behaviors between light and strange quarks [1]:

- Flavour-specific kinks occurring at different temperatures
- Deviations of Hadron Resonance Gas (HRG) Predictions from Lattice Curves coincide with kinks

Does the transition from quark to hadron degrees of freedom occur at the same temperature for all quark flavours?

II. Sequential Hadronization



We model the idea of two chemical freeze-out (2CFO) temperatures:

- Strangeness Freeze-Out (SFO) occurs before Light Freeze-Out (LFO) $\ni T_S > T_L$

Using a state-of-the-art thermal model package, we will show the 2CFO approach produces a more natural explanation of Strangeness Enhancement across various system energies and system sizes.

III. Thermal FIST (The FIST) [2]

Configuration: Ideal HRG, Grand Canonical (GCE) and Strangeness Canonical (SCE)

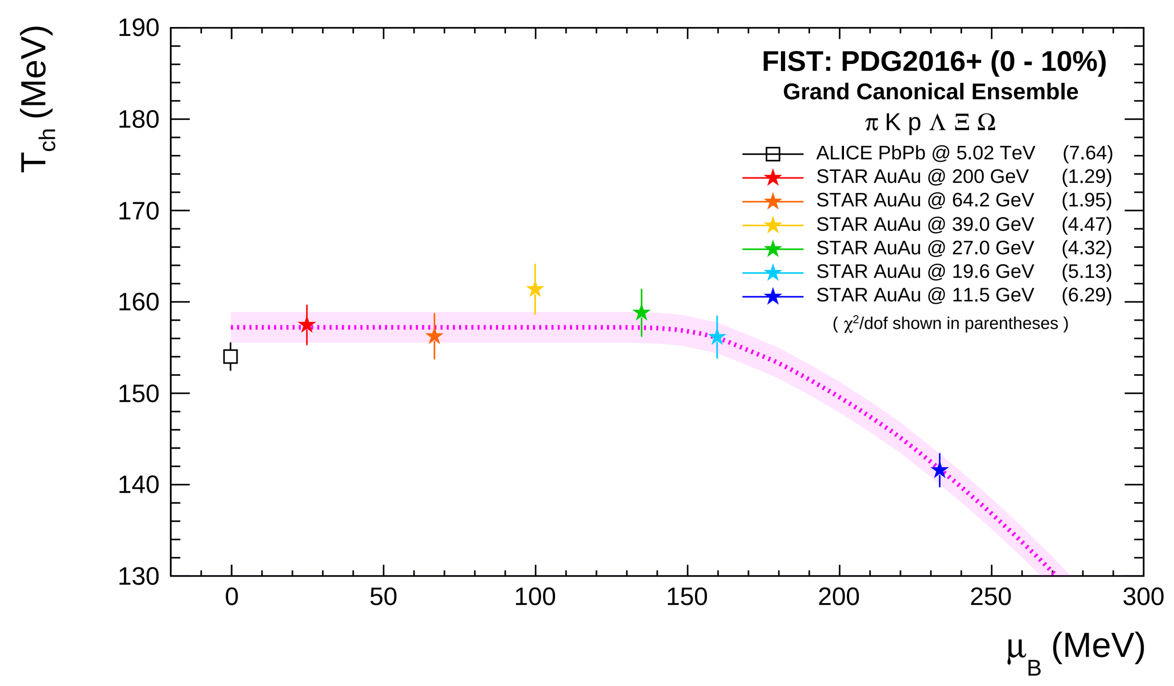
Hadronic Spectrum: **PDG2016+: 738 States [3]** (Includes *, **, *** and **** states from PDG)

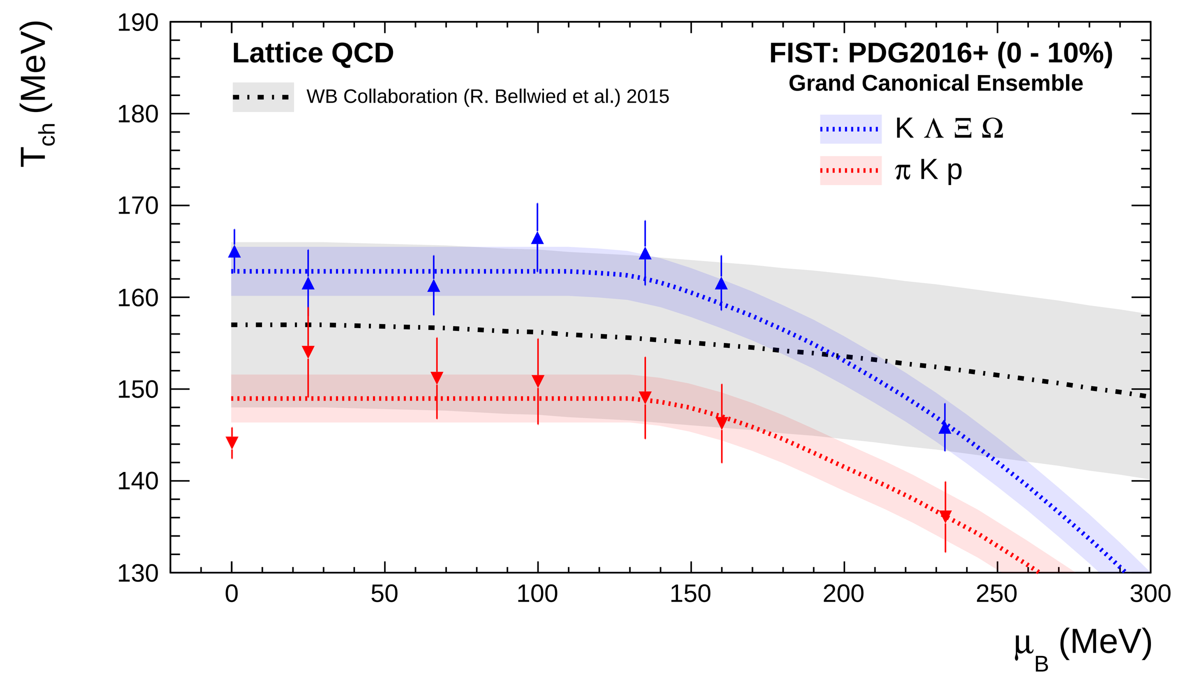
Yield Data: ALICE pp 7 TeV, pPb 5.02 TeV, PbPb 2.76 TeV, PbPb 5.02 TeV [4,5,6,7] and STAR AuAu 11.5 – 62.4 GeV [8,9]

References

[1] WB Collaboration. PRL. 111 (2013) 202302.
[2] V. Vovchenko, et al. JCPC. 244 (2019) 295.
[3] P. Alba, et al. PRD. 96 (2017) 034517.
[6] ALICE Collaboration. Nature Phys. 13 (2017) 535.
[5] ALICE Collaboration. PLB. 728 (2014) 25.
[4] ALICE Collaboration. PRC. 88 (2013) 044910.
[7] ALICE Collaboration. NPA. 982 (2019) 1.
[8] STAR Collaboration. PRC. 96 (2017) 044904.
[9] STAR Collaboration. arXiv:1906.03732 [nucl-ex].
[10] WB Collaboration. PLB. 751 (2015) 559.

IV. Energy Dependence of Flavour Specific Freeze-out Temperatures





Our thermal fits to π K p Λ Ξ Ω for most central (0 - 10%) A-A Collisions are shown on the left and flavour specific fits (light and strange) are shown on the right. Bands show splined fits of the extracted freeze-out temperature (T_{ch}) as a function of the baryochemical potential (μ_B).

$T|_{\mu_B=0}$ values:

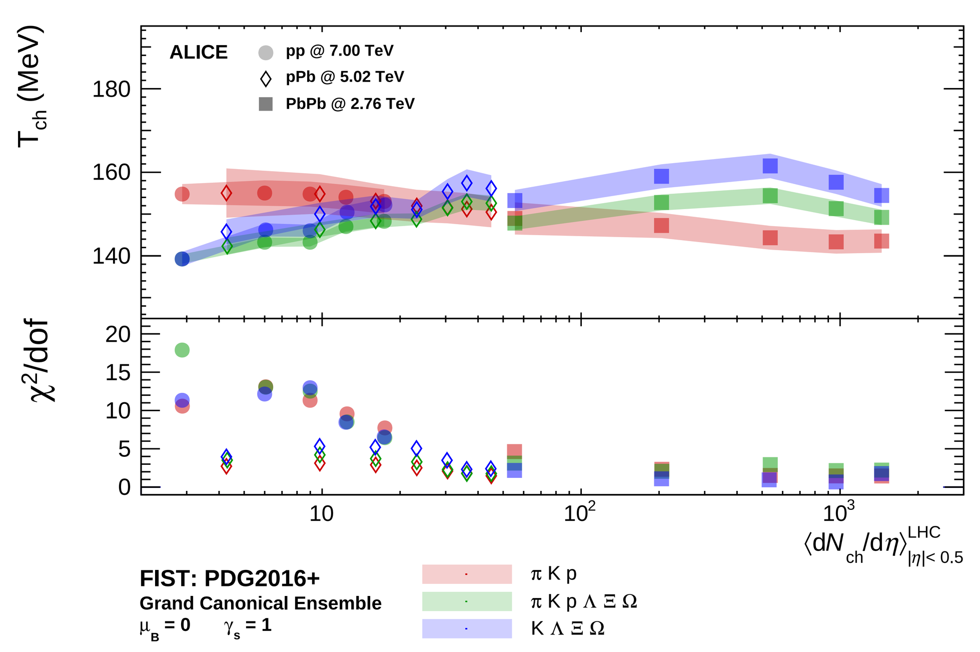
$$\mathbf{T_{ch}^{light} = 150 \pm 2.5 \text{ MeV}}$$
$$T_{ch}^{full} = 158 \pm 3.8 \text{ MeV}$$
$$\mathbf{T_{ch}^{strange} = 163 \pm 4 \text{ MeV}}$$
$$T_{LQCD} = 157 \pm 9 \text{ MeV [10]}$$

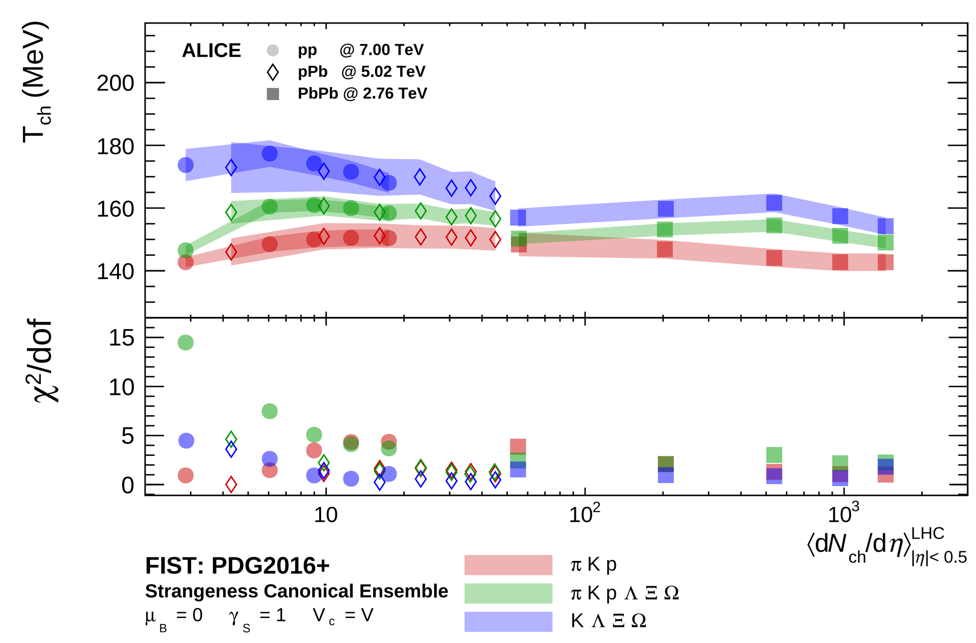
We show flavour-dependent freeze-out temperatures across the analyzed system energies.

By eye, T_{ch}^{light} and $T_{ch}^{strange}$ lines converge at high μ_B

If we use temperatures extracted from yields that serve as susceptibility (i.e. order parameter) proxies, then our measurements may signal a critical point at high μ_B.

V. Grand Canonical vs. Strangeness Canonical Ensembles at ALICE

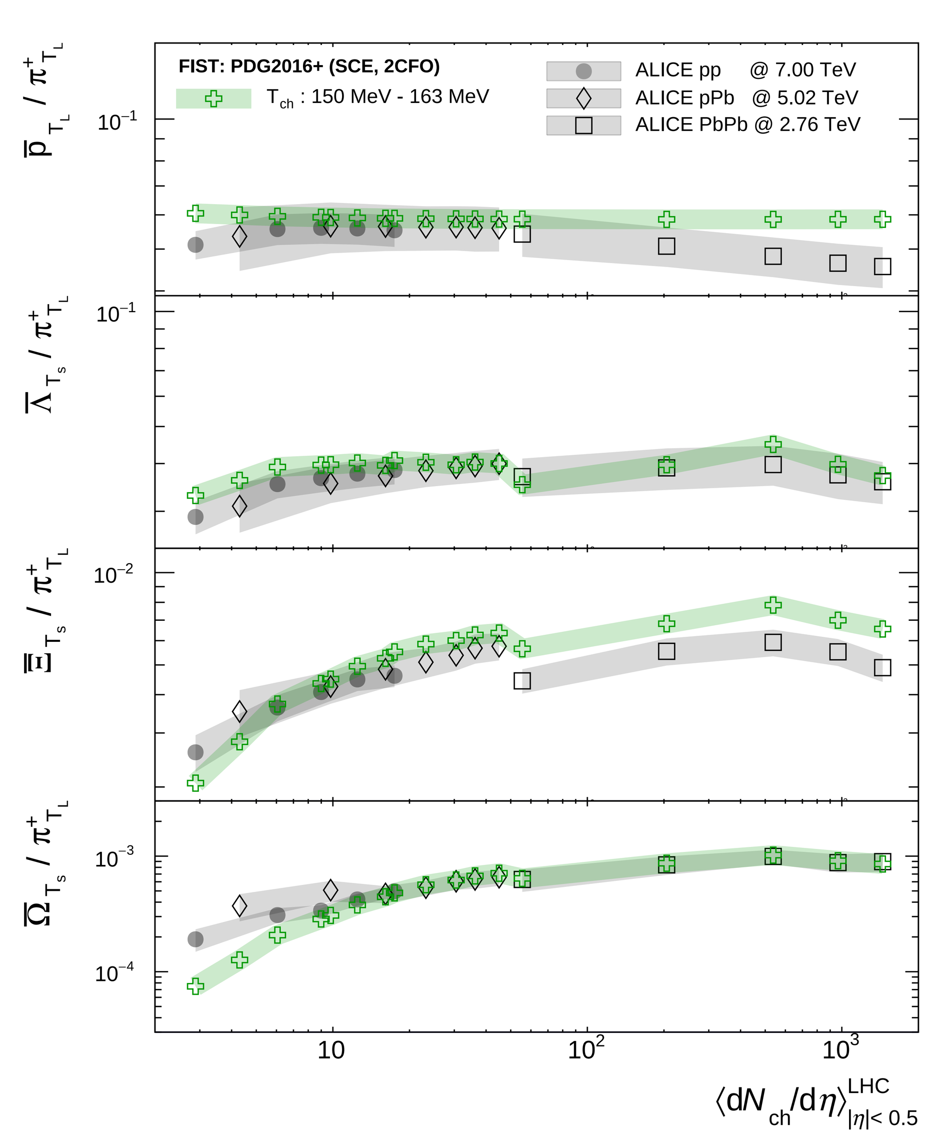




SCE approach adequately describe all three systems consistently than the GCE approach:

- For $dN_{ch}/d\eta < 10$, quality of **full** fit still deteriorates
- **Temperature splitting creates better quality of fits throughout light and strange fits**

VI. System Size Dependence of Chemical Freeze-out Temperatures



We show the ALICE data can be well-described by the SCE thermal model using flavour dependent freeze-out temperatures in ratios

ALICE Data is shown in grey and our calculations using the 2CFO approach are shown in green

π^+ and $\bar{p}$ yields calculated at at $T_{ch}^{light} = 150$ MeV

$\bar{\Lambda}$ $\bar{\Xi}$ $\bar{\Omega}$ yields calculated at $T_{ch}^{strange} = 163$ MeV

We can describe strangeness enhancement in the SCE approach with two freeze-out temperatures without a canonical suppression factor.

For $dN_{ch}/d\eta > 10$, strangeness appears saturated; potentially a signature of a Quark Gluon Plasma.

VII. Concluding Remarks

We confirm a flavour separation of extracted T_{ch} values from LHC down to lower RHIC energies. At LHC energies, flavour separation prevails in small systems. We show Strangeness Enhancement can be described without the need for canonical suppression via the 2CFO approach. Further studies are ongoing.