Freezeout- role of the missing resonances

Sandeep Chatterjee
AGH-UST, Krakow

AGH

National Science Centre Poland

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In collaboration with Debadeepti Mishra, Bedangadas Mohanty, Subhasis Samanta

Freezeout:

Bottom-up vs Top-down

Bottom-up

D E T E C T O R

π, K, p,..., K^*, d,..

↑

Freezeout:
Cooper-Frye
(+ Afterburner)

Evolution:
Hydro/Transport

Initial Conditions:
Glauber(+ CGC)

Top-down

D E T E C T O R

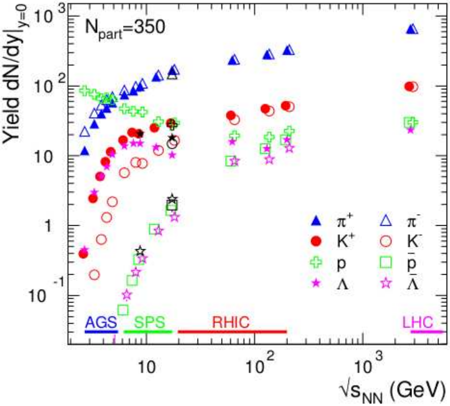
π, K, p,..., K^*, d,..

↓

Economical description of $\langle dN/dy \rangle$, $d^2N/dydp_T$;
Takes us to where they froze: the freezeout hypersurface

d.o.f at freezeout: hadrons;
provides the hadronic background to any study of the QGP. For an access to the fireball prior to freezeout$\rightarrow$necessary to comprehend freezeout.

Hadron yields: Probes of the freezeout surface



from Andronic 1407.5003

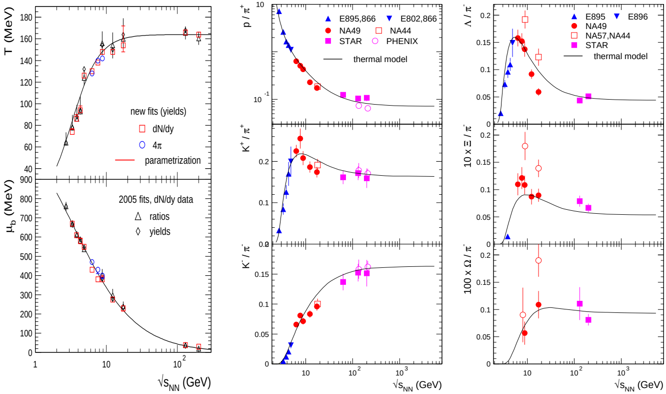
The single freezeout ansatz (1CFO)

- Simplest ansatz: The hadronic fireball is in complete thermal and chemical equilibrium at the time of chemical freezeout (CFO) when the hadron yields are frozen Andronic, Becattini, Castorina, Cleymans, Munzinger, Redlich, Satz, Stachel, Xu $\sim$ 1990-...
- We have a Grand Canonical Ensemble for the hadronic fireball labelled by
  - temperature T,
  - hadron chemical potentials μ_h. Under complete chemical equilibrium, all possible forward and backward hadronic reactions rates are equal. Then all hadron chemical potentials can be expressed only in terms of three chemical potentials $\mu_{B,Q,S}$

$$\mu_h = B_h \mu_B + Q_h \mu_Q + S_h \mu_S$$

  - To be fitted from experiments: T, μ_B and volume V (μ_Q and μ_S internally solved).

Satisfactory description by 1CFO



Andronic, Munzinger, Stachel 2009

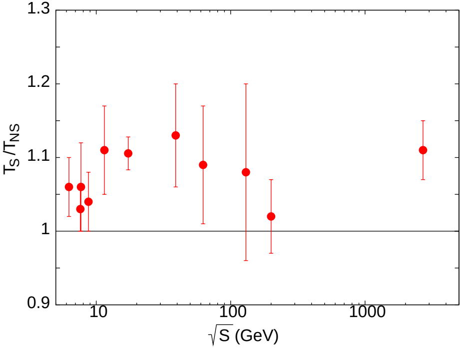
Beyond 1CFO

- Interaction vs Expansion: Flavor hierarchy in cross-sections $\rightarrow$ flavor hierarchy in freezeout
  SC, Godbole, Gupta (2013); Bugaev et. al. (2013);
- Hadronization $\rightarrow$ Freezeout: Flavor hierarchy indicated from different thermodynamic quantities/in medium hadron masses on the lattice and QCD models
  Bellwied et. al. (2013); Rincon et. al. (2014);
- Flavor hierarchy in freezeout: a natural extension of 1CFO

Implementing flavor hierarchy in HRG

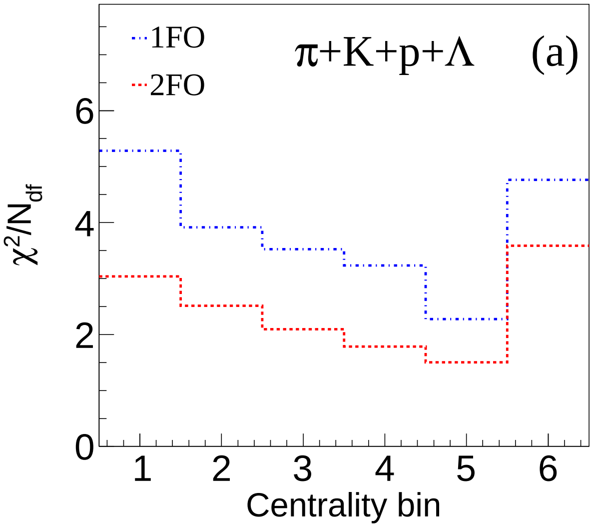
- HRG yields functions of properties of hadrons(m_i, r_i, a_i, b_i..)$\times$fireball(T, $\mu_{B,Q,S}$,R)
- Flavor hierarchy could be introduced into fireball properties (2CFO) Bellwied et. al. (2013); SC, Godbole, Gupta (2013); Bugaev et. al. (2013)
- Flavor hierarchy could be introduced into hadron properties Alba, Vovchenko, Gorenstein, Stoecker (2016)

2CFO: Results



SC, Godbole, Gupta 2013

2CFO: Results (LHC Spectra)



SC, Mohanty, Singh 2014; also ${}^{3}_{\Lambda}H/{}^{3}He$ at RHIC: SC, Mohanty 2014

How do the missing resonances influence ?

- The hadron resonance spectrum is the only input to HRG calculations. Standard practice is to account for all confirmed resonances from the PDG.
- Lattice computations / Quark models suggest more resonances than observed so far Capstick, Isgur (1986); Ebert et. al (2009); Edwards et. al. (2012)
- Strangeness fluctuation and strangeness-baryon correlation on the lattice do not compare well with HRG (PDG2012) (agreement improves on the addition of missing resonances), analysing strange anti-baryon to baryon ratios indicate a 5-8 MeV drop in strangeness freezeout T Bazavov et. al. (2014)

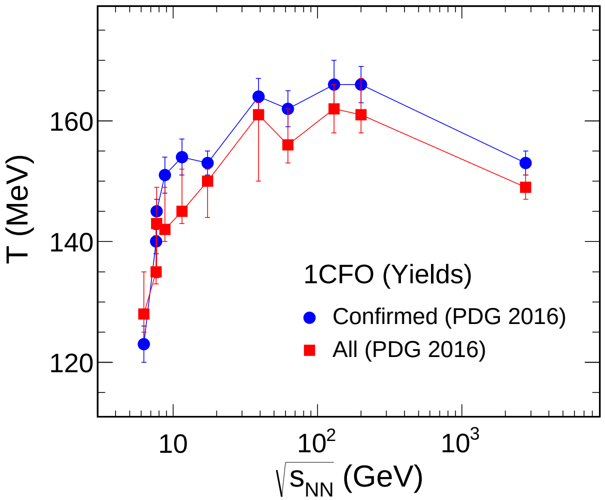
How do the missing resonances influence ?

- Latest PDG (PDG2016) already has confirmed several of these model/lattice predicted states and included others in the list of suspects
- Detailed comparisons show that the list of all resonances listed in the PDG2016 (confirmed and suspected) provides satisfactory description of strangeness thermodynamics on the lattice Alba et. al. (2017)
- Motivates to study the effect of this updated hadron spectrum on the freezeout parameters: How much does the freezeout T drop in 1CFO ? What happens to the evidence of 2CFO earlier seen with PDG2012 ?

Treating the suspected resonances

- Apart from the primordial yields, secondary yields due to the feeddown from unstable resonances is an important ingredient of the HRG framework
- Estimating this feeddown demands knowledge of the BRs of the unstable resonances to the stable hadrons
- While PDG lists the BRs of most of the confirmed resonances, those of the unconfirmed ones are unknown
- We have modelled the BRs of such resonances from their neighboring (in mass) resonances with known BRs and same quantum numbers.

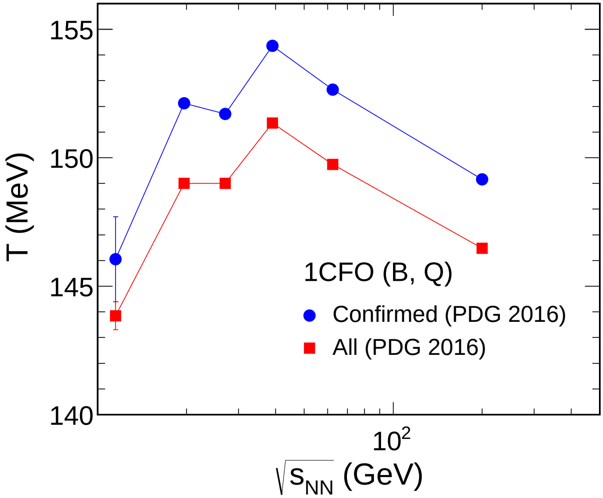
Results: 1CFO



Results: 1CFO

- Though central values indicate $2-4\%$ cooling, uncertainties due to the BRs systematics are large
- We also extract the freezeout parameters from conserved charge fluctuations; the BRs systematics of the suspected states do not enter here while their quantum numbers are well known

Results: 1CFO



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- Analysis of the conserved charge fluctuations clearly reveal $2-3\%$ cooling

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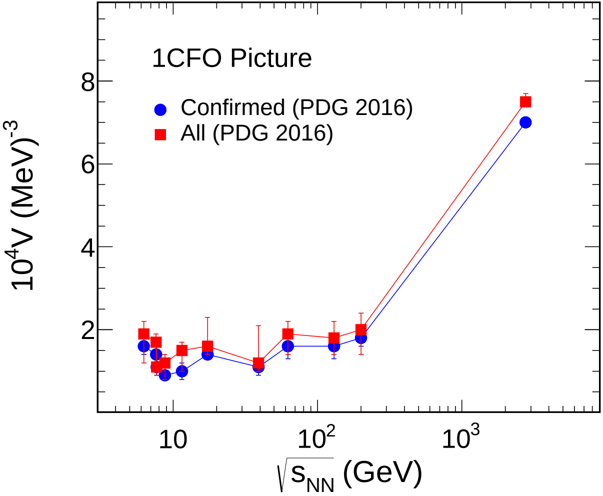

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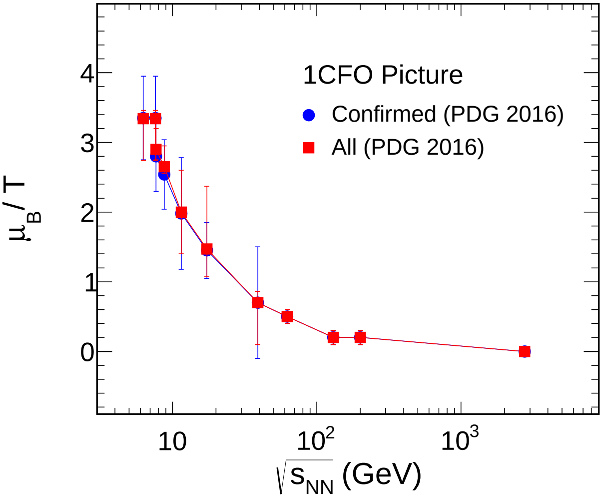

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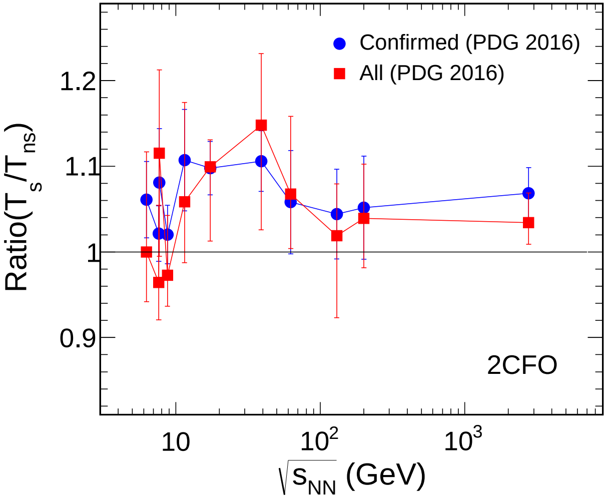
- The volume grows by $\sim 10-30\%$.
- μ_B/T does not change; meson to baryon ratio is not affected by the missing resonances
- What happens to flavor hierarchy ?

Results: 2CFO



2CFO: PDG2012 vs PDG2016 vs PDG2016+beyond

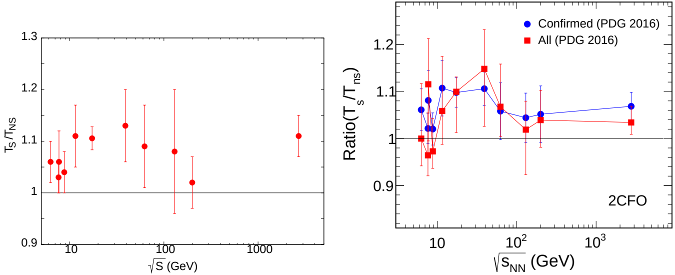
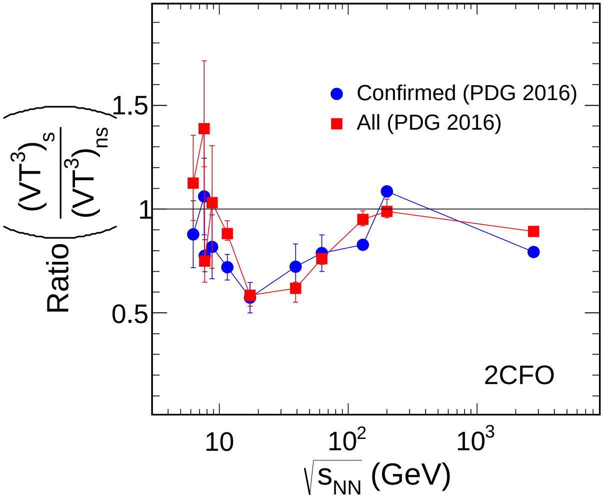


Figure : Left: PDG2012 (SC, Godbole, Gupta (2013)), Right: PDG2016, PDG2016+beyond (current analysis)

Results: 2CFO



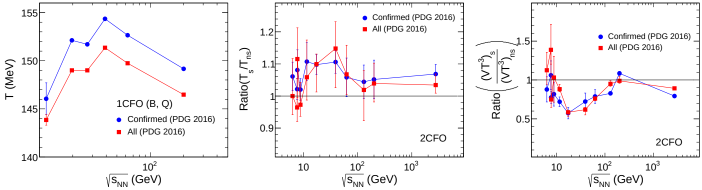
Summarising

- Freezeout analysis is in principle dependent on the input hadron spectrum. Comparison of thermodynamics on the lattice and HRG imply significant role for the missing/yet to be confirmed resonances. With reasonable assumption of the BRs, their role on freezeout parameters can be analysed
- Within 1CFO, addition of the unconfirmed resonances lead to $2-6\%$ cooling and $10-30\%$ larger volume while keeping μ_B/T unchanged
- Systematic uncertainties due to the unknown BRs do not allow us to draw a firm conclusion on the freezeout parameters when using hadron yields data
- Analysis with data on conserved charge fluctuation confirm cooling by $2-4\%$ due to the extra resonances

Summarising

- The statement on flavor hierarchy largely remains unaffected due to additional resonances. Though discussions on 2CFO was triggered by the LHC data, the most promising region to look for it seems to be the intermediate energy range. Within $\sqrt{s_{\rm NN}} \sim 10 - 100$ GeV, a very prominent broad peak (valley) like structure is seen for T_s/T_{ns} (V_s/V_{ns}).
- Below $\sqrt{s_{\rm NN}} \sim 10$ GeV, central values suugest a flip in the hierarchy on addition of the extra resonances, though a clear statement can not be made owing to the large systematic uncertainties.
- Challenge: Data seems to suggest flavor hierarchy. However, flavor hierarchy could be introduced in hadron properties (VdW parameters: a, b) or fireball properties (2CFO: T, V, μ_B) as discussed here. How to distinguish the two scenarios ?

Take Home



THANK YOU FOR YOUR ATTENTION