Strangeness freezeout- role of system size and missing resonances

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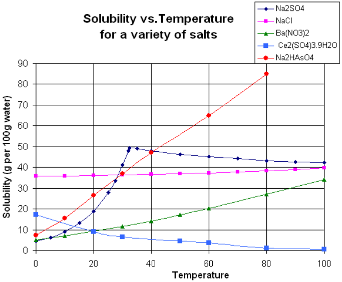
Examples of freezeout in multi-component systems



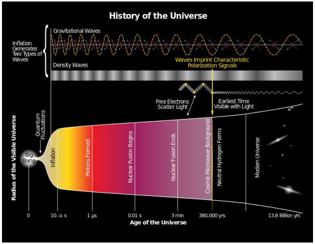


Figure : *Left*: Salt solution on your table top, *Right*: Universe in the early times

Heavy Ion Collisions ?

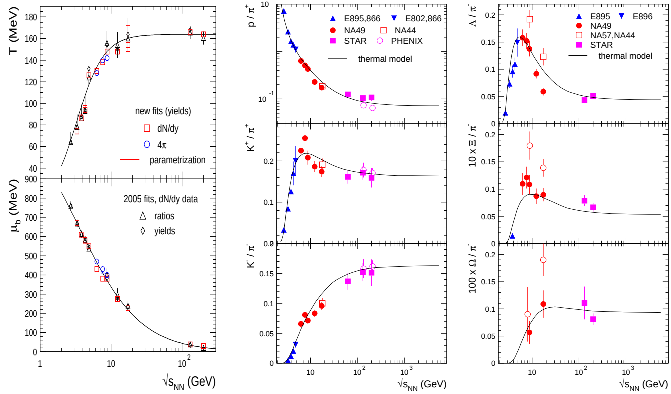
The single freezeout ansatz (1CFO)

- 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).

Excellent description by 1CFO



Andronic, Munzinger, Stachel 2009

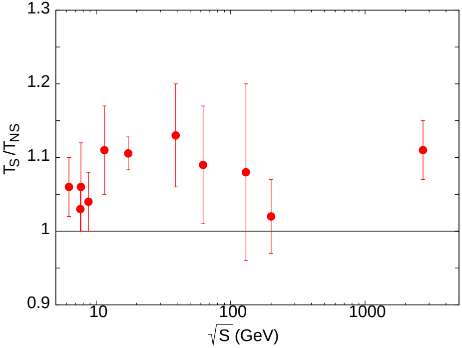
Interpreting freezeout

- 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); see R. Bellwied's talk
- Interaction vs Expansion $\rightarrow$ Freezeout ?
  - Flavor hierarchy in cross-sections $\rightarrow$ flavor hierarchy in freezeout SC, Godbole, Gupta (2013); Bugaev et. al. (2013); see J. T. Rincon's talk
- Flavor hierarchy in freezeout: a natural extension of 1CFO

Implementing flavor hierarchy in HRG

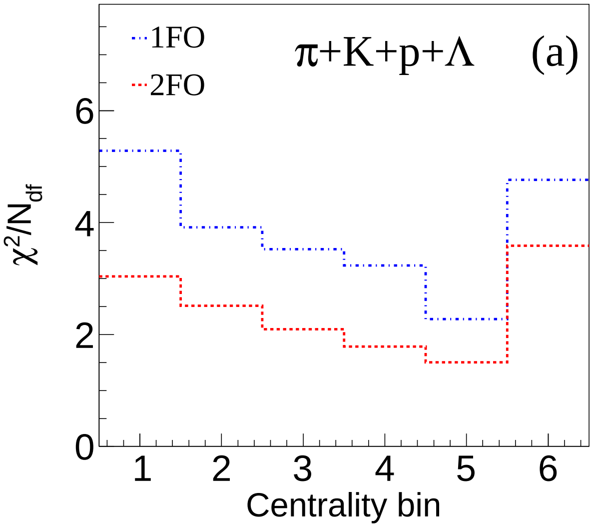
- HRG yields functions of properties of hadrons(m_i, r_i,..)$\times$fireball(T, $\mu_{B,Q,S}$,R)
- Flavor hierarchy could be introduced into hadron properties (Alba, Vovchenko, Gorenstein, Stoecker (2016))
- Flavor hierarchy could be introduced into fireball properties (2CFO)
  (Bellwied et. al. (2013);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

2CFO: Results



SC, Godbole, Gupta 2013

2CFO: Results (LHC Spectra)



SC, Mohanty, Singh 2014; also ${}^3_\Lambda H/{}^3He$ 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.
- Detailed comparisons show that the list of all resonances listed in the PDG (confirmed and suspected) is sufficient see C. Ratti's talk

How do the missing resonances influence ?

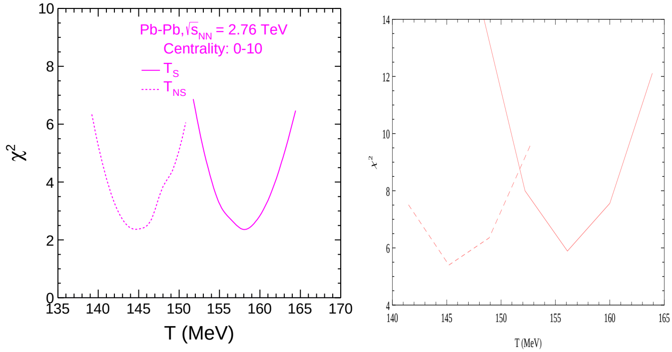
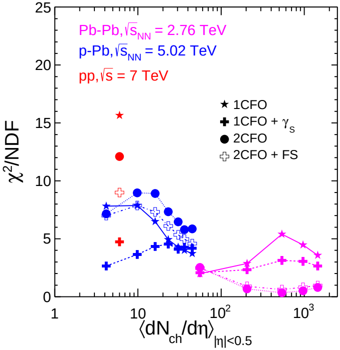
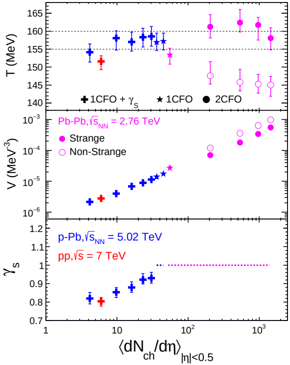


Figure : *Left:* $\geq$ ***, *Right:* All

System Size dependence of freezeout scheme



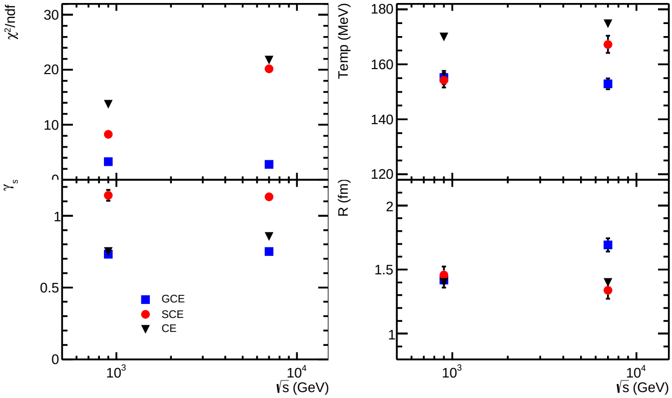


SC, Dash, Mohanty 2016

Choice of ensemble at the LHC

- Standard viewpoint: Canonical Ensemble correct for all system sizes $\rightarrow$ System open wrt energy exchange (T), close wrt other conserved charges (B, Q, S)
- For large system size, Canonical approximated as Grand-Canonical, as in HICs
- At LHC ?

LHC: True Grand Canonical Ensemble from small to large system size?



Das, Mishra, SC, Mohanty 2016

LHC: True Grand Canonical Ensemble from small to large system size?

- Standard viewpoint: Canonical Ensemble correct for all system sizes $\rightarrow$ System open wrt energy exchange (T), close wrt other conserved charges (B, Q, S)
- At LHC for the choice of acceptance of $|\eta| < 0.5$, only a slice of the system formed (pp to PbPb) observed $\rightarrow$ open wrt all conserved charges
- One possible test for this hypothesis: Measure yields for broader η range $\rightarrow$ Canonical ensemble expected to be restored for $\eta > \eta_C$

Summarising

- 1CFO provides very good description of hadron abundances across a wide range of beam energies. A closer scrutiny seems to give hints for physics beyond 1CFO $\rightarrow$ flavor hierarchy in freezeout ?
- Flavor hierarchy could be introduced in hadron properties, fireball properties (2CFO). Challenge: An observable that will discriminate the two schemes.
- Additional resonances do not change the results for 2CFO at LHC.
- Analysis of the hadron yields within 2CFO is sensitive to system size: 2CFO preferred for only large system while 1CFO for small systems
- At LHC, grand canonical ensemble seems to be the right choice for ensemble across system size (η acceptance effect ? Canonical ensemble restored for larger η acceptance ?)

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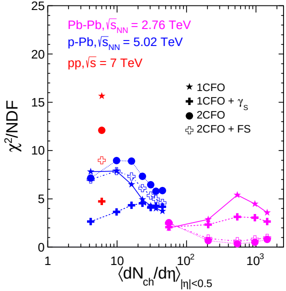
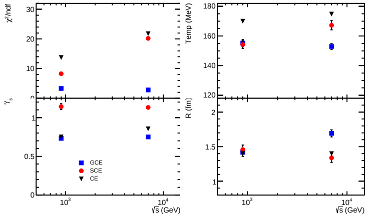
Take Home





THANK YOU FOR YOUR ATTENTION