

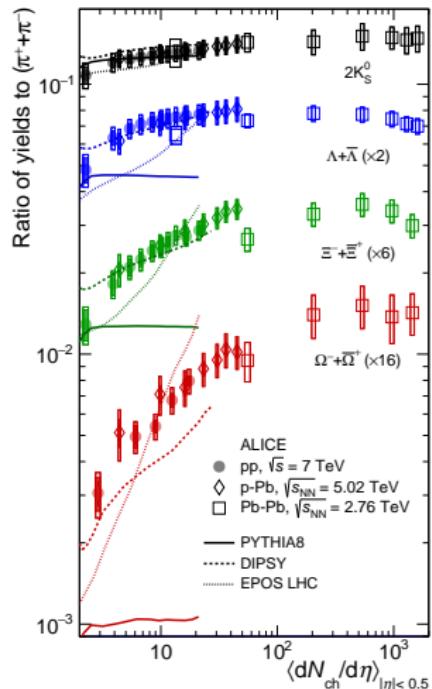
Strangeness in relativistic heavy ion collisions

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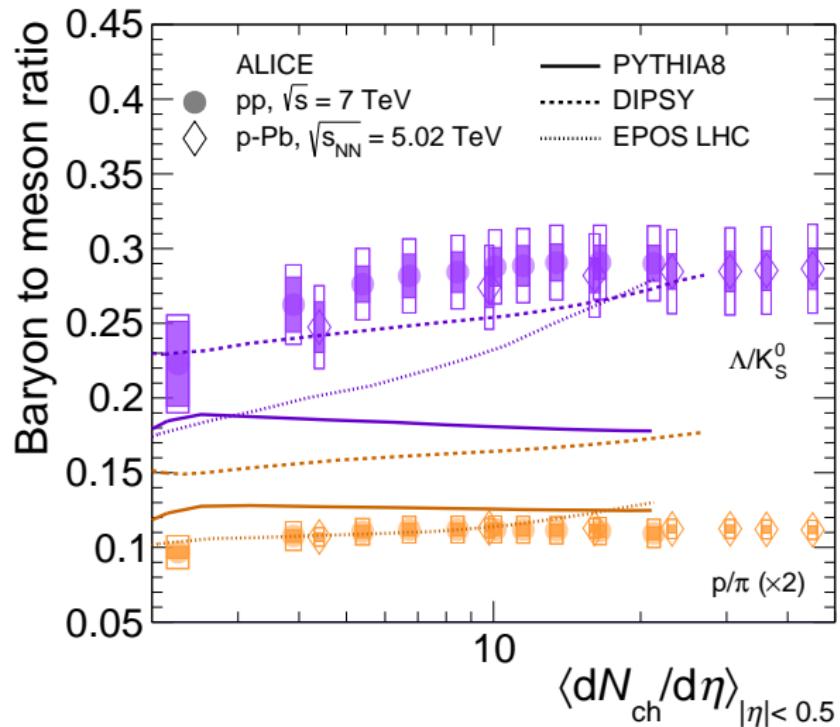
CETHENP, VECC
25 - 27 Nov, 2019

Strange Trends With System Size Of Strangeness

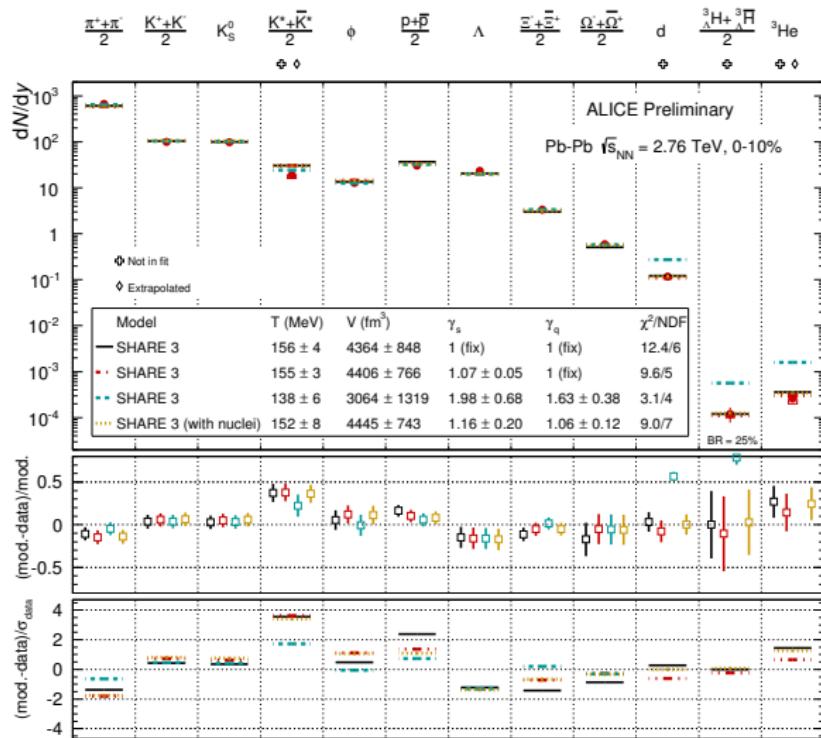
Chemistry in small system: strange to non-strange - rises with system size



Chemistry in small system: like flavor ratio - flat with system size

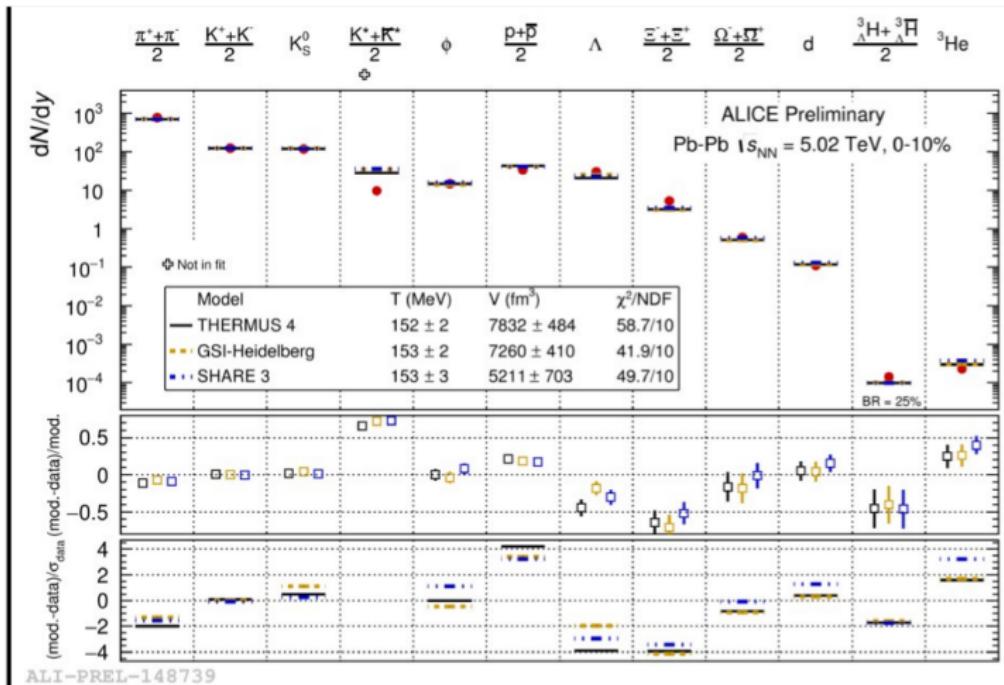


Chemistry in large system: tension in unlike flavor



ALI-PREL-74481

Chemistry in large system: tension in unlike flavor



Freezeout:

Bottom-up

vs

Top-down

D E T E C T O R

$\pi, K, p, \dots, K^*, d, \dots$

Freezeout:
Cooper-Frye
(+ Afterburner)

Evolution:
Hydro/Transport

Initial Conditions:
Glauber(+ CGC)

D E T E C T O R

$\pi, K, p, \dots, K^*, d, \dots$

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 → necessary to
comprehend freezeout.

Understanding the system size dependence of chemistry in Top-down approach

D E T E C T O R

$\pi, K, p, \dots, K^*, d, \dots$

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the single freezeout thermal model claim is:

- The hadronic fireball is in complete thermal and chemical equilibrium at the time of chemical freezeout (CFO) when the hadron yields are frozen
- 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 μ_B, μ_Q, μ_S

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

- To be fitted from experiments: T , μ_B , V (μ_Q and μ_S from constraints).
- thus yields that vary over several orders of magnitude and across several orders of $\sqrt{s_{\text{NN}}}$ can be understood within an equilibrium thermal model framework i.e. can be parametrised by 2 parameters T and μ_B (if hadron ratios) / 3 parameters T , μ_B and V (if hadron yields)

suggested variants to complete equilibrium single freezeout scenario

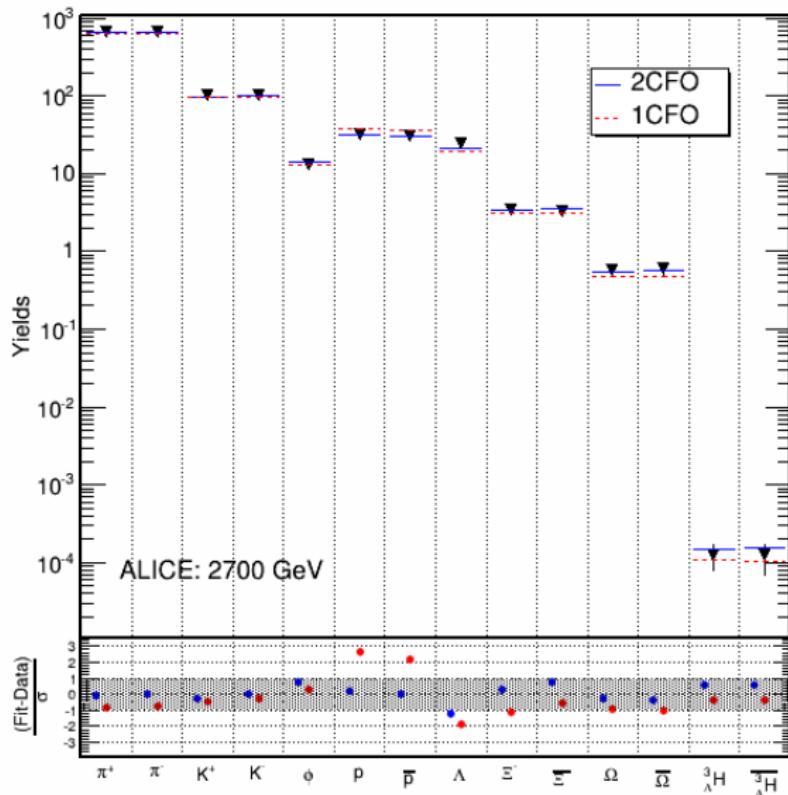
- deviation from complete equilibrium, introduce additional fugacity factors for light and strange flavors Petran et al 2013
- deviation from single towards multiple freezeout scenarios: simplest application- separate freezeout for non-strange and strange hadrons

Bellwied et al, SC et al, Bugaev et al 2013; Rincon et al 2014

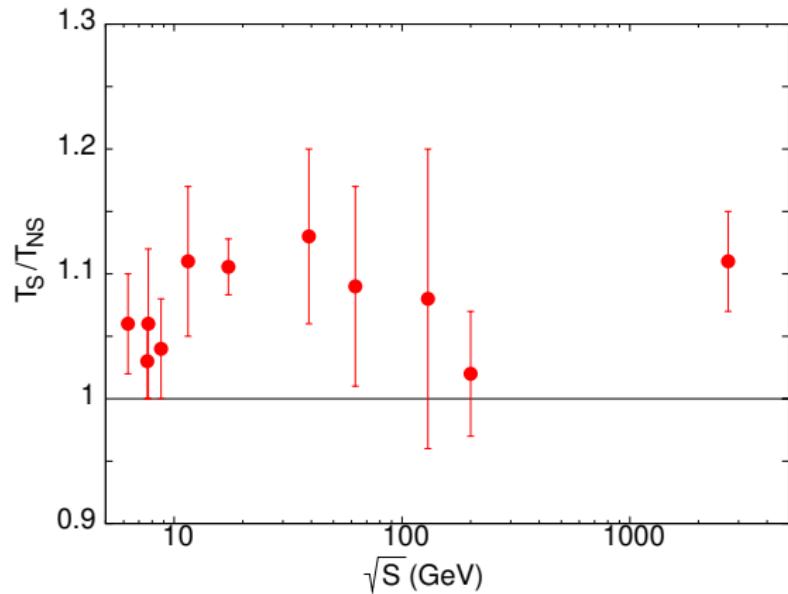
2CFO scheme

- Kaon to pion ratio $\sim e^{-\Delta m/T}$ rapidly falls as the system cools. Hence strangeness changing reactions freezeout earlier due to the depletion of the kaon bath
- Motivates to propose separate CFO for (strange+hidden strangeness) and non strange hadrons: 2CFO
- T_s, V_s, μ_{B_s} characterise the strange surface
- $T_{ns}, V_{ns}, \mu_{B_{ns}}$ characterise the non-strange surface
[SC, Godbole, Gupta 2013](#)

Resolution at LHC

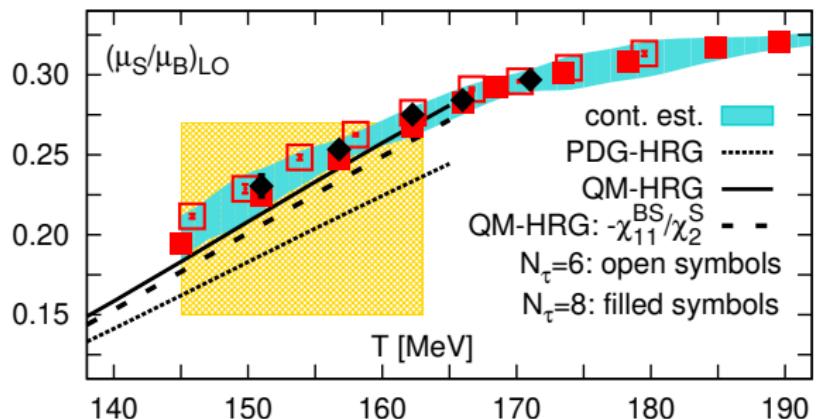


Flavor hierarchy: peaks at $\sqrt{s_{\text{NN}}} \sim 10 - 100$ GeV



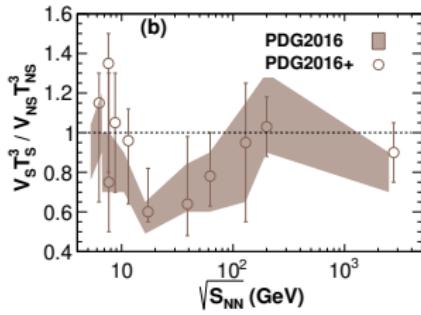
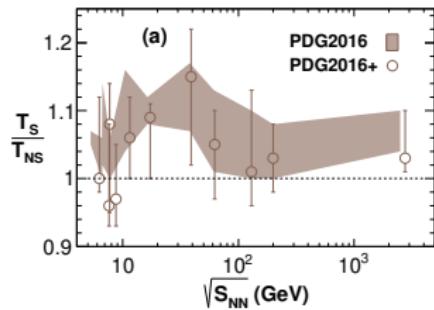
SC, Godbole, Gupta 2013

Effect of missing states



HotQCD 2014

Flavor hierarchy: survives missing resonances contribution



SC, Mishra, Mohanty, Samanta 2017

Ratios

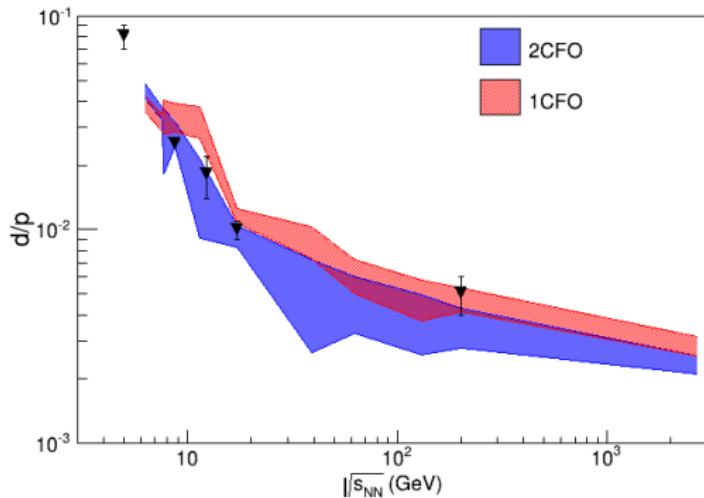
- Unlike Flavor Ratio (R^{UF}):

$$R_{2\text{CFO}}^{\text{UF}} \sim \left(\frac{T_s}{T_{ns}} \right)^{3/2} \left(\frac{V_s}{V_{ns}} \right) R_{1\text{CFO}}^{\text{UF}}$$

- Like Flavor Ratio (R^{LF}):

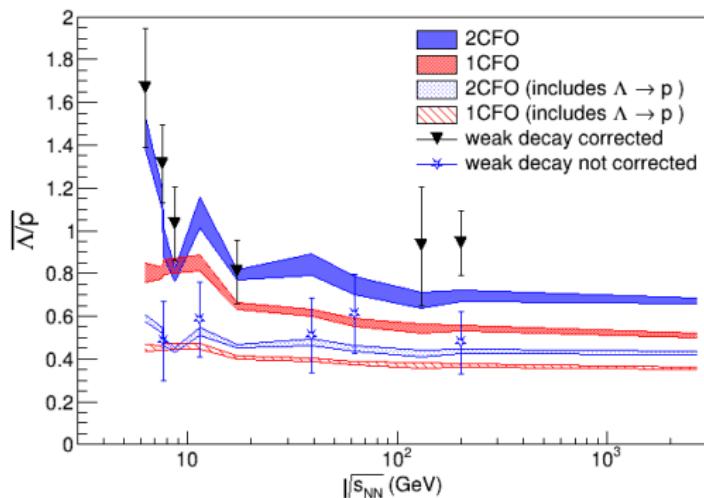
$$R_{2\text{CFO}}^{\text{LF}} \sim R_{1\text{CFO}}^{\text{LF}}$$

Like Flavor Ratio



SC, Mohanty 2014

Unlike Flavor Ratio



SC, Mohanty 2014

1CFO vs 2CFO

- How to interpret the improvement of χ^2/N_{df} in 2CFO over 1CFO ?
- Is it really physics beyond 1CFO or interplay of parameters and χ^2 ?
- The issue lies in the fact that the particle ratios / yields are not parameter independent predictions of thermal models.
- Ask: Can we construct parameter independent predictions of the 1CFO thermal model ? If yes, that could be tested without the confusion of number of parameters vs χ^2 debate.

Parameter free prediction

- Primary yield

$$N_i^P = \left(\frac{V_i T_i g_i m_i^2}{\pi^2} \right) \sum_{l=1}^{\infty} \frac{(-a)^{l+1}}{l} K_2 \left(\frac{l m_i}{T_i} \right) e^{l(B_i \mu_{B,i} + Q_i \mu_{Q,i} + S_i \mu_{S,i})/T_i}$$

- Boltzmann approximation $m_i/T \gg 1$ good for all except pions

$$N_i^P = \left(\frac{V_i T_i g_i m_i^2}{\pi^2} \right) K_2 \left(\frac{m_i}{T_i} \right) e^{(B_i \mu_{B,i} + Q_i \mu_{Q,i} + S_i \mu_{S,i})/T_i}$$

- Particle to anti-particle ratio

$$\left(N_i^P / \overline{N_i^P} \right) = R_i^P (\hat{\mu}_{iB}, \hat{\mu}_{iQ}, \hat{\mu}_{iS}) = \exp (2 (B_i \hat{\mu}_{iB} + Q_i \hat{\mu}_{iQ} + S_i \hat{\mu}_{iS}))$$

- In 1CFO, only 3 independent fugacity factors corresponding to the 3 conserved charges. Hence, only 3 independent particle to anti-particle ratios. The rest are constrained.

Parameter free prediction

- We focus on the following class of parameter-free conditions

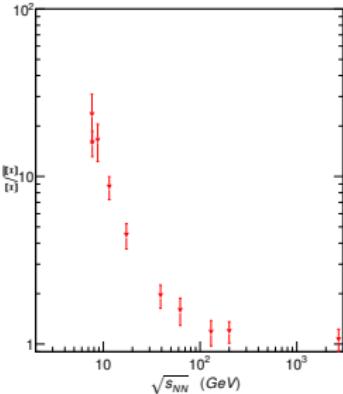
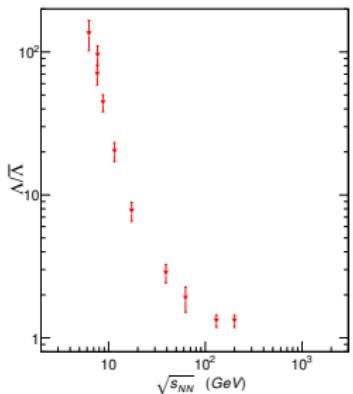
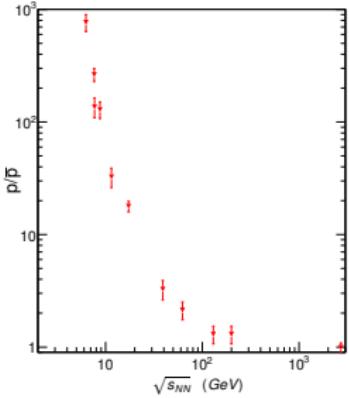
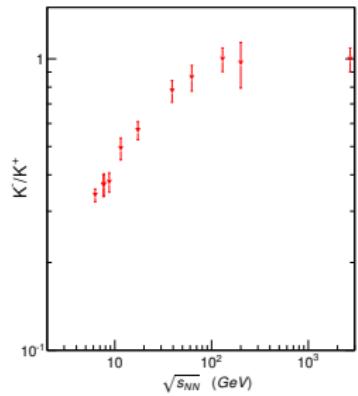
$$\mathcal{R}_{\Lambda p K}^p = \frac{R_\Lambda^p}{R_p^p R_K^p} = 1$$

$$\mathcal{R}_{\Xi \Lambda K}^p = \frac{R_\Xi^p}{R_\Lambda^p R_K^p} = 1$$

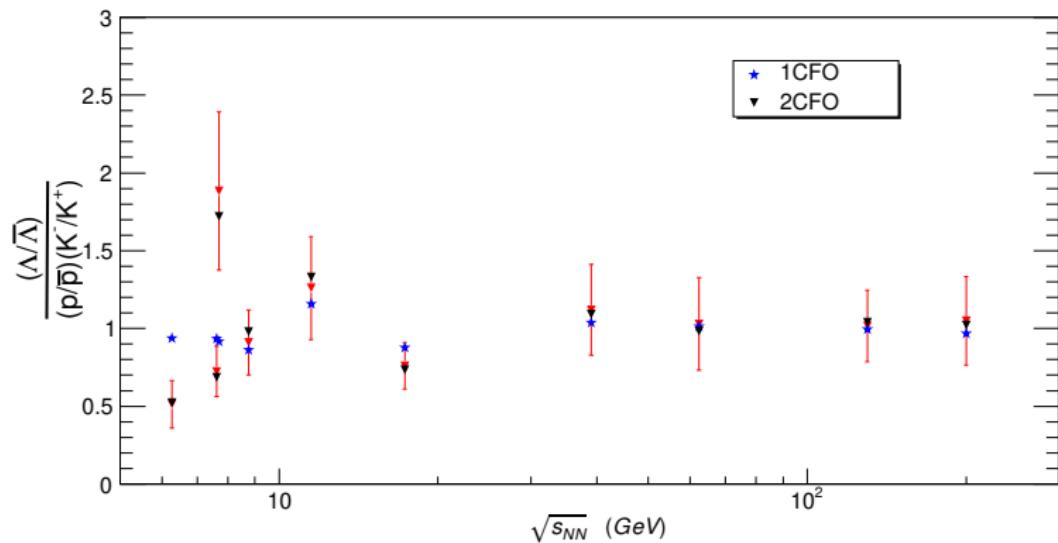
..... all such ratios where the quantum numbers add up to zero.

- Secondary feeddown contribution can spoil this. Feeddown can be systematically included in thermal models. Typically, their influence < 20%. Hence deviations of more than 20% in data is interesting.

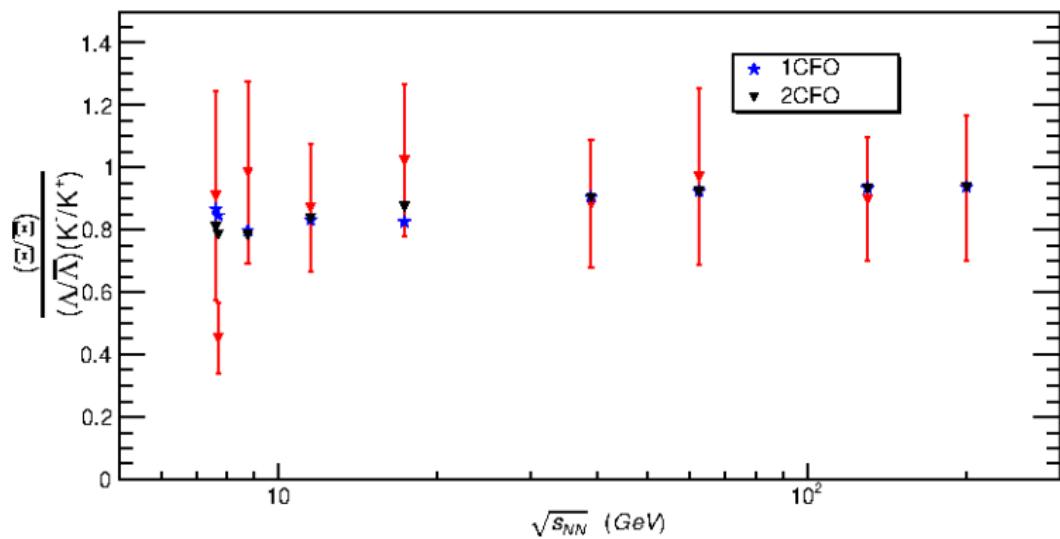
Data: Single ratios



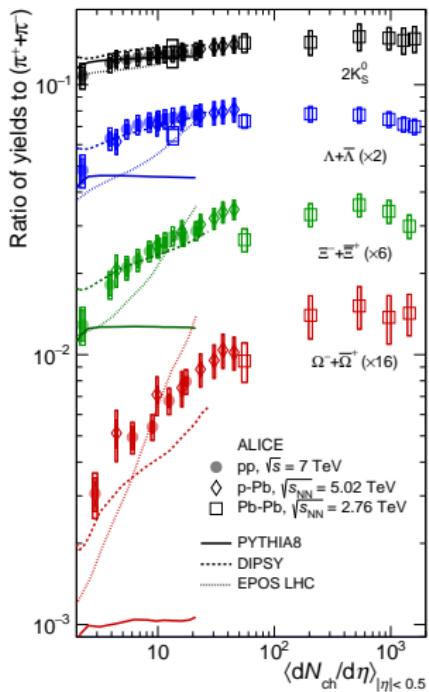
Data - 1CFO - 2CFO: Triple ratios



Data - 1CFO - 2CFO: Triple ratios

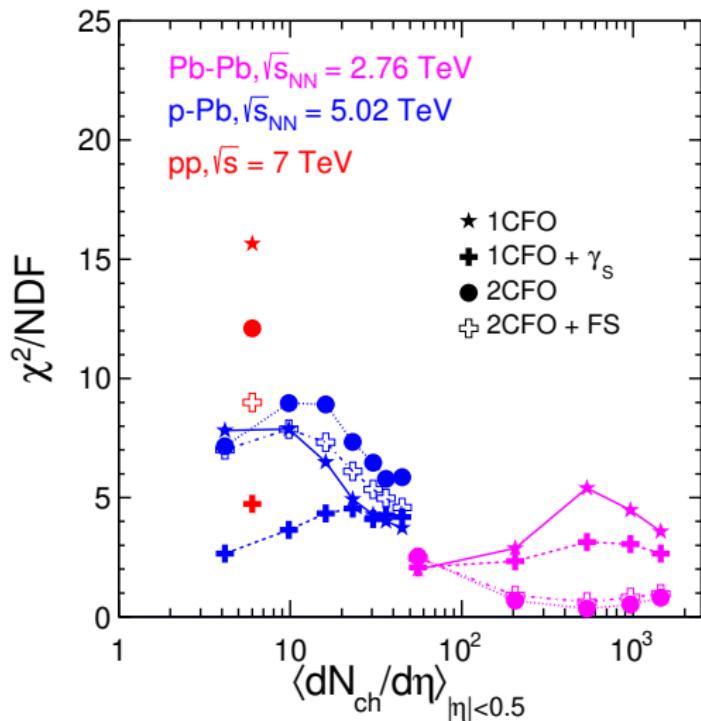


Now revisiting...

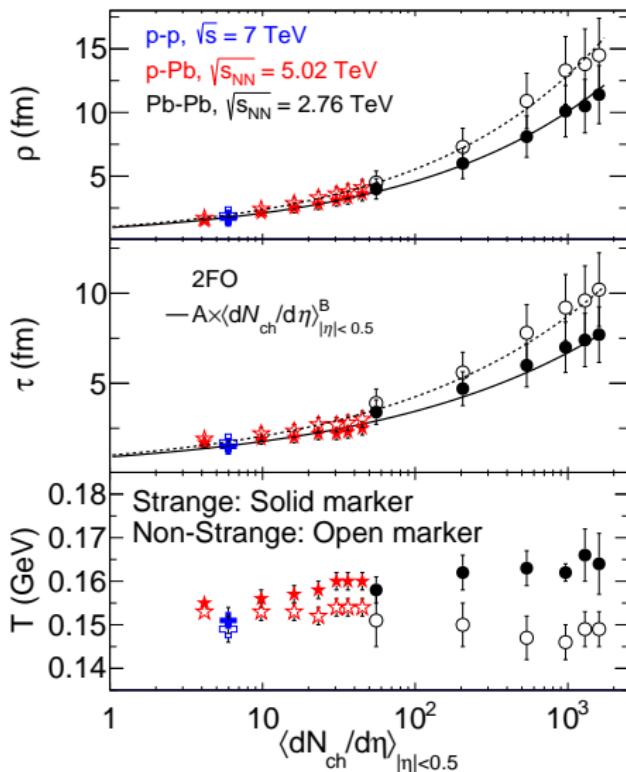


ALICE 2016

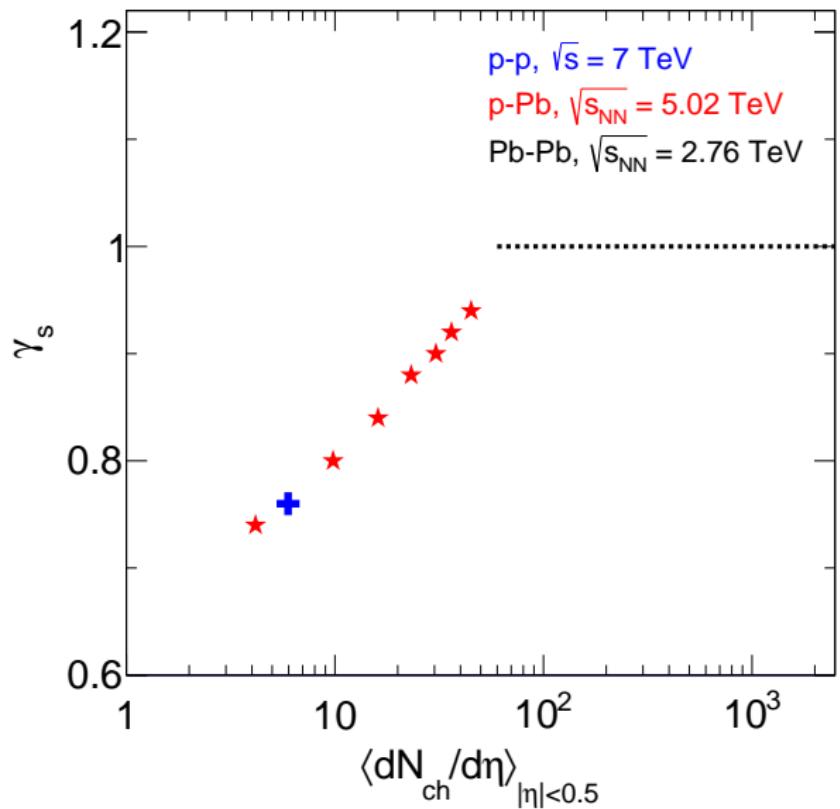
1CFO - 2CFO: System size dependence



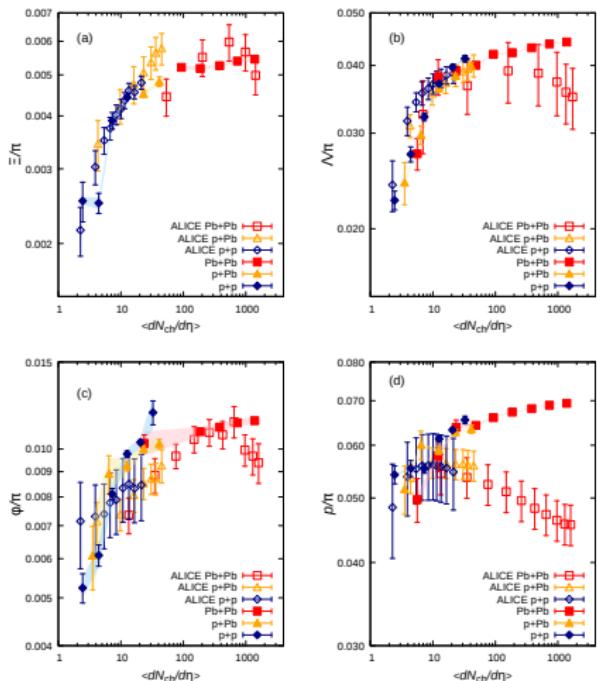
1CFO - 2CFO: System size dependence



Strangeness out of equilibrium in small system?

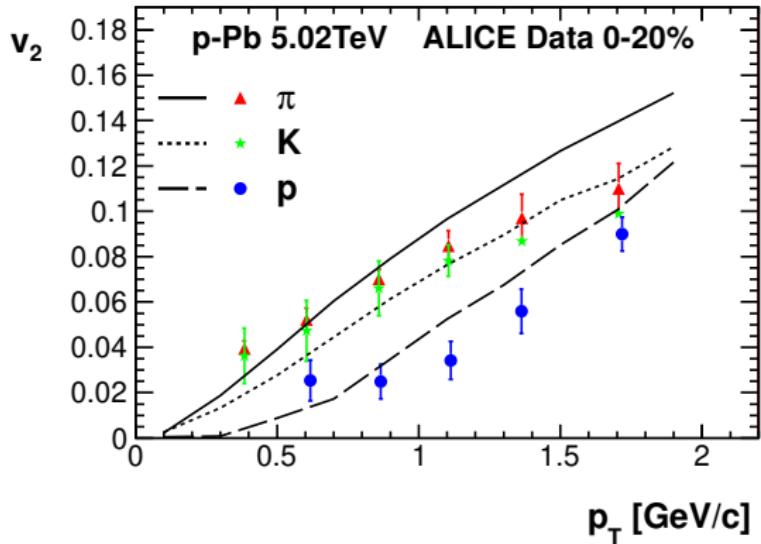


further support from dynamical approach



core corona approach: [Kanakubo, Tachibana, Hirano 1910.10556](#)

..but what happened to the flow??



seems thermalized in a flowing medium!

Bozek, Broniowski, Torriori 2013

..and there seems like some convergence on this..

CONCLUSIONS

B. Schenke, C. Shen, P. Tribedy, e-Print: arXiv:1908.06212

- Qualitative description of v_n data seems to require dominance of final state interactions for $dN_{\text{ch}}/d\eta \gtrsim 10$
- Even if final state is described by realistic hydrodynamics, the initial momentum anisotropy can affect final observables
- With one set of parameters, we describe a wide range of data for different systems at RHIC & LHC
- A delicate balance between initial and final state effects in pp? Could help constrain model, but one needs to be careful:
Other effects like hydro-fluctuations, conservation laws at particle sampling, etc. can be very important here

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so here is the strange tension

with decreasing system size

- flow suggests equilibration / thermalization (hydro → Cooper-Frye → thermal equilibrium)
- chemistry suggests out of equilibrium
- this is similar to the classic case of the charm in heavy ion collisions..production is not thermal, still flows!

Summarising

- is strange in small systems \equiv charm in heavy ions ?

THANK YOU