Suppression of the LHC p/π ratio due to the QCD mass spectrum

Jacquelyn Noronha-Hostler

Universidade de Sao Paulo
with C. Greiner, M. Beitel, I. Shovkovy, J. Noronha, and the v-USPhydro group

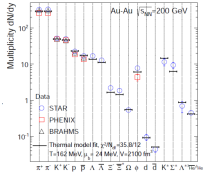
Quark Matter 2014 : May 21st, 2014 : Darmstadt, Germany

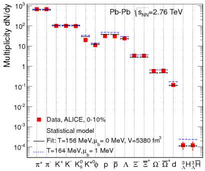
Outline

Thermal fits at RHIC vs. LHC

RHIC vs. LHC

Thermal Fits worked at RHIC but overpredict p/π at LHC





Braun-Munzinger, Andronic, Redlich, and Stachel- various works

Extending the mass spectrum worked at RHIC, what about LHC?:

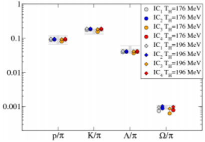


FIG. 27: Plot of the various ratios including all initial conditions defined in Tab. II. The points show the ratios at $T = 110$ MeV for the various initial conditions (circles are for $T_H = 176$ MeV and diamonds are for $T_H = 196$ MeV). The experimental results for STAR and PHENIX are shown by the gray error bars.

JNH, C. Greiner, and I. Shovkovy PRL100(2008)252301 and PRC81(2010)054909

Improves thermal fits at RHIC

JNH, et al.,PRC82(2010)024913 Other suggestions:

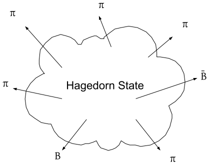
- Final State interations- PRL110,042501(2013)
- Different hadronization temperatures for light and strange quarks- PRD85,014004(2012)

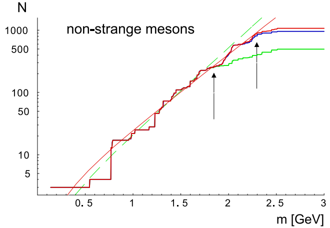
Can extend the mass spectrum using Hagedorn States

Hagedorn States

"fireballs consist of fireballs, which consist of fireballs..."

- Proposed an exponentially increasing mass to explain spectra in $p - p$ and $\pi - p$ scattering
- Original model included hadronic states up to $\Delta(1232)$





Broniowski,Florkowski,Glozman,PRD70,117503(2004)

- Exponential mass spectrum
- Constant T_H: ↑ energy of system, ↑ new particles, NOT T_H

Form of Hagedorn Spectrum

Degeneracy of Hagedorn states

$$\rho(M) = \int_{M_0}^{M} \frac{A}{\left[m^2 + (m_0)^2\right]^a} e^{\frac{m}{T_H}} dm \qquad (1)$$

- $a = 3/2$, HS decay into 2 particles*
- $a = 5/4$, HS decay into multiparticles
- $a = 0$, ???

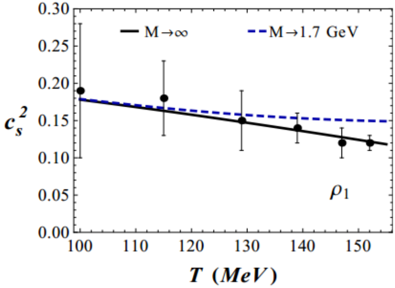
*Most likely, according to Frautschi PRD3(1971)2821-2834

	T_H (MeV)	A	m_0 (MeV)	a
ρ_1^{**}	252	2.84 (1/GeV)		0
ρ_2^{***}	180	0.63 (GeV$^{3/2}$)	0.5	$\frac{5}{4}$
ρ_3^{***}	175	0.37 (GeV^2)	0.5	$\frac{3}{2}$

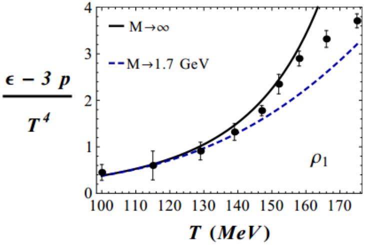
** Taken from Majumder & Muller 2010 (fitted to BMW)
*** Fitted to BMW (T_c 160 MeV) JNH, et. all, PRC86(2012)024913 , PRL103(2009)172302
- Original fits JNH,C. Greiner, I. Shovkovy PRL 2008

currently using only non-strange, mesonic HS

Equation of State- HS fit lattice data to higher temperatures



JNH, Jorge Noronha, Carsten Greiner PRC86 (2012) 024913

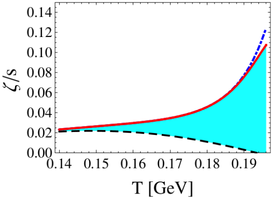


JNH, Jorge Noronha, Carsten Greiner PRC86 (2012) 024913
see also Majumder & Muller 2010

Hadron resonance fits up until $T = 130 - 140$ MeV whereas Hagedorn states fit up until $T \approx 155$ MeV.

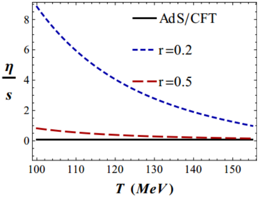
Extended Mass Spectrum and Transport Coefficients

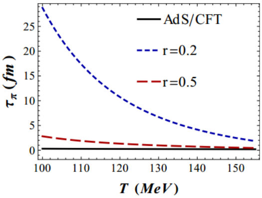
ζ/s



JNH, Jorge Noronha, and Carsten Greiner, PRL103(2009)172302

η/s



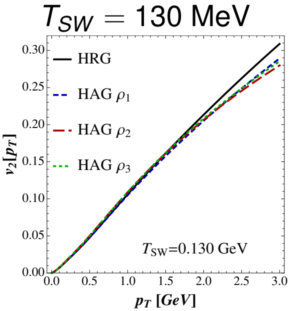


JNH, Jorge Noronha, Carsten Greiner
PRC86(2012)024913 and PRL103(2009)172302

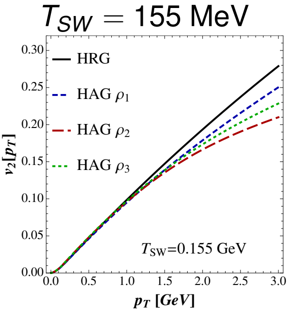
HS allow for η/s to drop to the KSS limit- smooth transition for hydro

Sufficiently near T_c, η/s can be close to the viscosity bound already in the hadronic phase!!!!

Extended Mass spectrum and Elliptical Flow



JNH, et al , PRC89(2014)054904



JNH, et al , PRC89(2014)054904

Calculations within v-USPhydro (PRC88(2013)044916, see poster H-23)

Higher switching temperatures, mean larger effect from HS. Need extended mass spectrum in decays!

Rate Equations for the Chem. Eq. Time of Hadrons

$n\pi \leftrightarrow HS \leftrightarrow n'\pi + X\bar{X}$

$$\frac{d\lambda_i}{dt} = \Gamma_{i,\pi}\left(\sum_n^{\infty} B_{i,n}\lambda_\pi^n - \lambda_i\right) + \Gamma_{i,X\bar{X}}\left(\lambda_\pi^{\langle n_{i,x}\rangle}\lambda_{X\bar{X}}^2 - \lambda_i\right),$$

$$\frac{d\lambda_\pi}{dt} = \sum_i \Gamma_{i,\pi}\frac{N_i^{eq}}{N_\pi^{eq}}\left(\lambda_i\langle n_i\rangle - \sum_n^{\infty} B_{i,n} n\lambda_\pi^n\right)$$
$$+ \sum_i \Gamma_{i,X\bar{X}}\langle n_{i,x}\rangle\frac{N_i^{eq}}{N_\pi^{eq}}\left(\lambda_i - \lambda_\pi^{\langle n_{i,x}\rangle}\lambda_{X\bar{X}}^2\right),$$

$$\frac{d\lambda_{X\bar{X}}}{dt} = \sum_i \Gamma_{i,X\bar{X}}\frac{N_i^{eq}}{N_{X\bar{X}}^{eq}}\left(\lambda_i - \lambda_\pi^{\langle n_{i,x}\rangle}\lambda_{X\bar{X}}^2\right)$$

$\lambda = \frac{N}{N^{eq}}$, N is the total number of each particle, its equilibrium value is N^{eq}. π's and HS begin in chemical equilibrium

Hydrodyanamical Expansion

Use an isentropic expansion...

Find T(t) for the 5% most central collisions

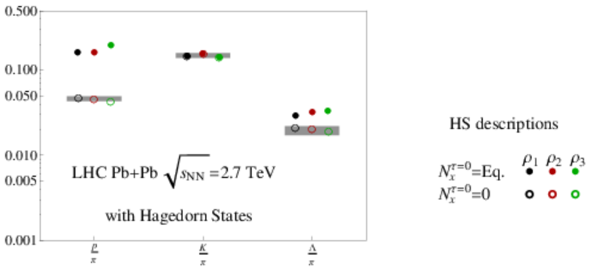
$$\frac{S_\pi}{N_\pi}\int\frac{dN_\pi}{dy}dy = s(T)V(\tau) = const.$$

Volume

$$V_{eff}(\tau\geq\tau_0) = \pi\,\tau\left(r_0 + v_0(\tau-\tau_0) + .5a_0(\tau-\tau_0)^2\right)^2$$

- $\tau_0 = 0.6$ and 1.0 fm for LHC and RHIC, respectively.
- Begin resonance decays at $T_{sw} = 155$ MeV
- T_{end} varies on Hagedorn State description

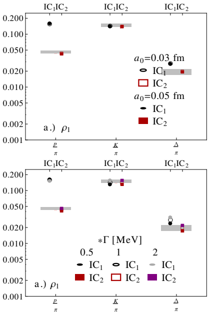
Results: Extended mass spectrum fits the low p/π at ALICE

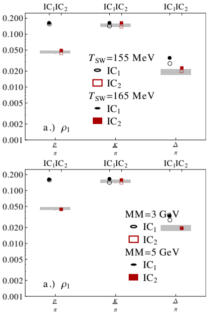


JNH and C. Greiner- to appear shortly

- Initially unpopulated p, K, and Λ's fit experimental data.
- When all hadrons begin in chem. eq. there is an overpopulation of p's!
- $T_{end} = 133$, 136, and 128 MeV for ρ_1-ρ_3, respectively
- The hydro expansion is significantly shorter at RHIC ($\Delta\tau \approx 5fm$ vs. $\Delta\tau \approx 10fm$ at LHC) whereas the time in the hadron resonance gas phase is roughly the same $\Delta\tau \approx 4-6fm$.

Results: Hagedorn States fits are robust

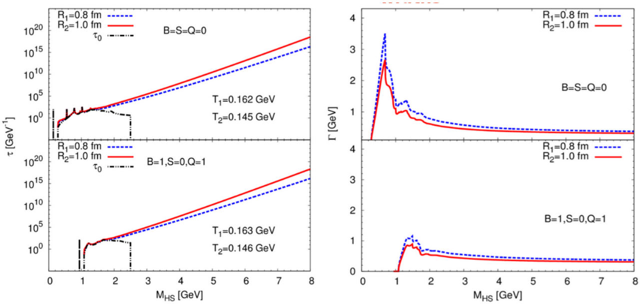




JNH and C. Greiner- to appear shortly

- Changing the expansion has almost no effects.
- Increasing the decay width still fits, decreasing is below data (slightly)
- Too high switching temperature=overpopulation
- Increased maximum mass of HS still fits data
- Similar results obtained for other HS descriptions (see upcoming paper)

The Future: Extended Mass Spectrum in Transport



Beitel, Gallmeister, and Greiner arXiv:1402.1458

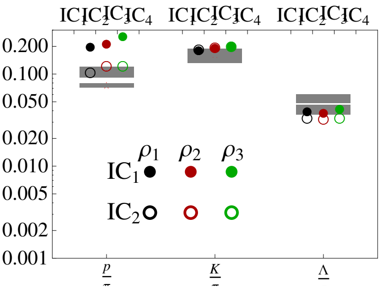
- Allows for resonance input, depends on mass, baryon number, strangeness, and charge.
- Includes all resonance decays.
- Maintains p_T dependence- can be coupled to hydro!
- Finds that the Hagedorn temperature is the same for mesons and baryons, matches well with known hadrons

Conclusions

Conclusions

- Both Lattice QCD and experimental results appear to indicate that heavier resonances are needed.
- Using the extended mass spectrum we are able to match experimental particle yields at both RHIC and ALICE
- When all hadrons begin at their chemical equilibrium values, an overpopulation of protons is produced.
- Hagedorn states are now available in transport methods and will be investigated with v-USPhydro in the future.
- Effects of the Hagedorn spectrum do not depend on the details of the mass distribution: the only true requirement seems to be exponentially rising number of states. Hence, predictions from these hadron gas models are robust.

Results: RHIC



- Slightly different setup as previous work but still matches data well
- May indicate a non-zero number of Λ's or that strange and/or baryonic Hagedorn states are needed

Otherwork on resonances

- Strangeness enhancement: P. Koch, B. Muller, and J. Rafelski
- $\bar{p} + N \leftrightarrow n\pi$ at SPS: R. Rapp and E. Shuryak
- Anti-hyperons at SPS: C. Greiner and S. Leupold.

Contribution of HS to Chemical Equilibrium Values

Effective $X = p$, K, or Λ

$$\tilde{N}_X = N_X + \sum_i N_i \langle X_i \rangle$$

Effective π's

$$\tilde{N}_\pi = N_\pi + \sum_i N_i \langle n_i \rangle$$

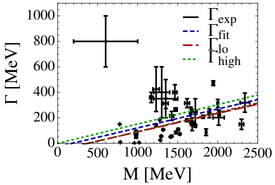
$\langle X_i \rangle$ and $\langle n_i \rangle$ are calculated within a microcanonical model

Liu, et.al. PRC68(2003)024905, JPG30(2004)S589, PRC69(2004)054002

Decay Width

- Linear fit (PDG)

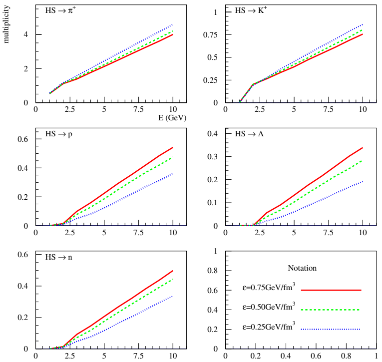
$$\Gamma_i = 0.15 m_i - 58 = 250 - 1000 \text{ MeV}$$



- $X\bar{X}$ (microcanonical)

$$\Gamma_{i,X\bar{X}} = \langle X \rangle \Gamma_i$$

$$\Gamma_{i,\pi} = \Gamma_i - \Gamma_{i,X\bar{X}}$$



C. Greiner et al., J.Phys.G31:S725-S732,2005.

$$\langle B \rangle \approx 0.06 \text{ to } 0.4$$
$$\langle K \rangle \approx 0.4 \text{ to } 0.5$$
$$\langle \Lambda \rangle \approx 0.01 \text{ to } 0.2$$

Branching Ratios

- Branching ratios for $n\pi \leftrightarrow HS$ are described by a Gaussian distribution

$$B_{i,n} \approx \frac{1}{\sigma_i \sqrt{2\pi}} e^{-\frac{(n - \langle n_i \rangle)^2}{2\sigma_i^2}}$$

- Average pion number (Liu, Werner, Aichelin, Phys. Rev. C 68, 024905 (2003).)

$$\langle n_i \rangle = 0.9 + 1.2 \frac{m_i}{m_p}$$

- Standard deviation

$$\sigma_i^2 = (0.5 \frac{m_i}{m_p})^2$$

- After cutoff $n \geq 2$, $\langle n_i \rangle \approx 3$ to 9 and $\sigma_i^2 \approx 0.8$ to 11
- For $HS \leftrightarrow n'\pi + X\bar{X}$, $\langle n_{i,x} \rangle = 2 - 4$
- assume $\langle n_{i,p} \rangle = 2 \langle n_{i,K} \rangle$