Chemical freeze-out in Au-Au collisions at RHIC

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Outline

Motivation

- Complete our previous studies at lower energies
  - Energy dependence
  - System size dependence
- Cross-check previous similar analyses at RHIC
  - Fitting a subset of particle ratios bias the outcome (arXiv:0707.4154)
  - The magnitude of the bias is not known without explicit comparison
  - New important data from STAR released $\rightarrow$ centrality dependence

Statistical hadronization model (1)

At RHIC grand-canonical ensemble seems most appropriate:

$$\langle N_j \rangle = \frac{(2J_j+1)V}{(2\pi)^3} \int d^3\mathrm{p} \left[\gamma_S^{-n_s} \mathrm{e}^{\sqrt{\mathrm{p}^2+m_j^2}/T - \boldsymbol{\mu}\cdot\mathbf{q}_j/T} \pm 1 \right]^{-1}$$

- Hadron radiation from a fireball is governed by equilibrium momentum distribution
- The underlying reason for the (apparent) equilibrium is being investigated
- Take into account all *** and **** hadrons up to mass 1.8 GeV and follow the decay chains to obtain final multiplicity
- Inclusion of resonances takes care of the strong interactions

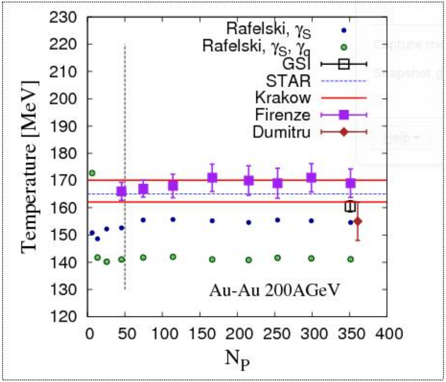
Statistical hadronization model (A-A at RHIC)

$$\left\langle \frac{dN_j}{dy} \right\rangle = \frac{(2J_j+1)\,V}{(2\pi)^3} \int d^3\mathrm{p}\; \left[\gamma_S^{-n_s} \mathrm{e}^{\sqrt{\mathrm{p}^2+m_j^2}/T - \boldsymbol{\mu}\cdot\mathbf{q}_j/T} \pm 1 \right]^{-1}$$

- Hadron multiplicities can be described by 4 free parameters
  - Temperature T
  - Baryon chemical potential μ_B (μ_S, μ_Q)
  - System volume V
  - at RHIC $V := \frac{dV}{dy}\Delta y \approx$ constant due to boost invariance
  - Strangeness phase-space occupancy factor γ_S
- The $\sqrt{s}$ and N_P dependence of the parameters *is not* known $\rightarrow$ fit to data $\rightarrow$ thermodynamics

Chemical freeze-out temperature at RHIC Au-Au 200AGeV

Inclusion of STAR data NECESSARY (primary tracks: too few dof)

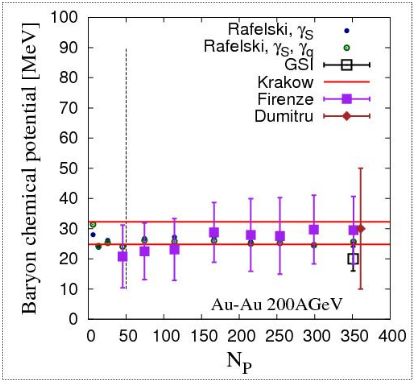


- Rafelski γ_S, γ_q: over-fitting PHENIX data
- Others agree with each other in-spite of (significant) differences in details

Everybody agree: No dependence on centrality

Vertical line: Finite system size enters the game (canonical ensembles at mid-rapidity?)

Baryon chemical potential at RHIC Au-Au 200 AGeV

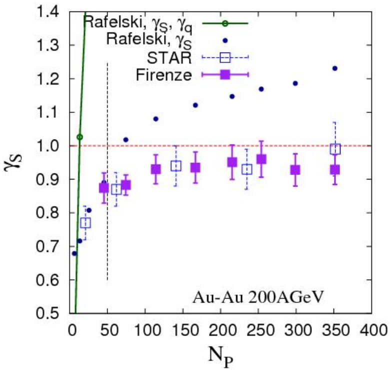


- Independent on data set
- Independent on version of SHM
- $\mu_B \in [20, 30]$MeV with relatively large uncertainty

Everybody agree: Weak dependence on centrality

Rapidity dependence of μ_B: strong dependence expected at large y

Strangeness saturation at RHIC Au-Au 200 AGeV



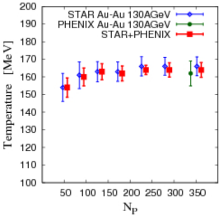
- THERMUS and Firenze in good agreement (ratios vs. yields)
- γ_S slightly below unity in the whole range

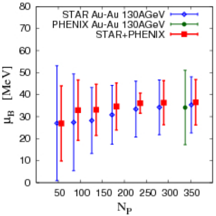
Weak dependence on centrality

Ultra-peripheral systems: seems as expected, BUT canonical effects especially important for (multi)strange hadrons

Chemical freeze-out at RHIC Au-Au 130 AGeV

GSI: central collisions T=165.5±5.5 ; μ_B=38±11 (ratios)
GSI: central collisions T=168 ; μ_B=34 ; dV/dy=1700fm^3 (yields)
Krakow: central collisions T=165±7 ; μ_B=41±5
Cape-Town (3 centralities): T≈165±5 ; $\mu_B \approx 35 \pm 5$





Different groups end up with the same T, μ_B
Centrality dependence similar to 200AGeV

$$T_{130} \lesssim T_{200} \;\; \mu_{B_{130}} \gtrsim \mu_{B_{200}}$$

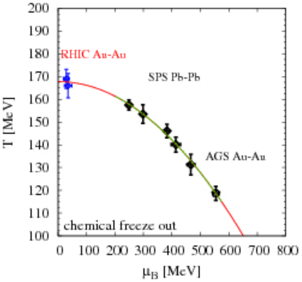
Limiting conditions at ($\langle N_P \rangle$>50) RHIC Au-Au collisions

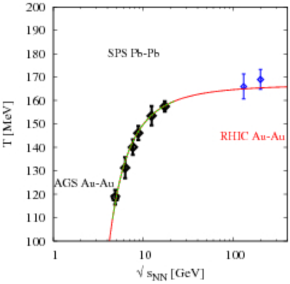
The thermodynamical state of matter is similar

- at all centralities
- at both energies

in Au-Au collisions at RHIC

At RHIC Au-Au collisions, limiting conditions have been reached?

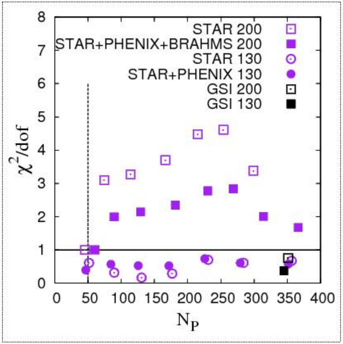




$T_{CFO} \approx T_{transition}$ at RHIC

Secondary corrections become important at RHIC

χ^2/dof values, remarkable differences among different groups



- $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ too few dof at RHIC (fits to these: $\chi^2/dof \approx 0.1$)
- STAR 130 and STAR 200: average $\frac{\frac{dN^e}{dy} - \frac{dN^{th}}{dy}}{\frac{dN^e}{dy}}$ ≈10% (12 different hadron species)

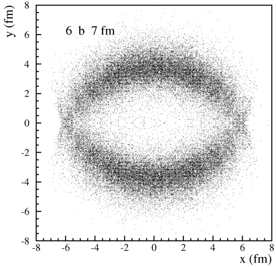
Fitting a subset of hadronic ratios (all fits to ratios so far)

(a) bias the fit (arXiv:0707.4154)

(b) lead to unrealistically small χ^2_{min}

Strangeness under-saturation due to core-corona effects?

(J. Cleymans, B. Kampfer, P. Steinberg, S. Wheathon, hep-ph 0212335 (2002))
F.B., M. Gazdzicki, A.K., J.M., R. Stock, Phys. Rev. C 69, 024905 (2004)
P. Bozek, Acta Phys.Polon.B36:3071 (2005)
C. Hohne, F. Puhlhofer, R. Stock, Phys. Lett. B 640, 96 (2006)
K. Werner, Phys. Rev. Lett. 98, 152301 (2007)

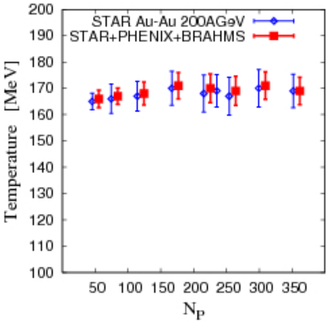


- Central core in full chemical equilibrium ($\gamma_S = 1$)
- In corona, p-p type of interactions (strangeness under-saturated)

STAR Au-Au 200 AGeV: ϕ meson

$$\frac{\langle \frac{dn}{dy} \rangle_{AA}}{N_P \langle \frac{dn}{dy} \rangle_{pppp}} \sim A + \frac{N_S}{N_P}(1 - A) \qquad A = \frac{f}{2n_0} \frac{\langle \frac{d\rho}{dy} \rangle_{core}}{\langle \frac{dn}{dy} \rangle_{pppp}}$$

N_S = number of single NN collisions, from Glauber model



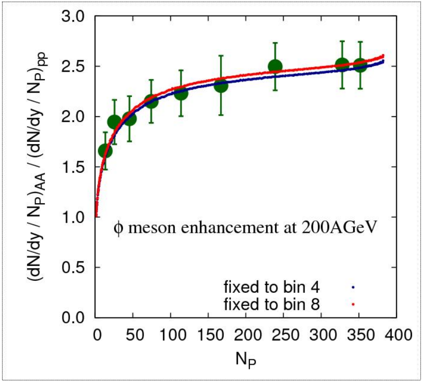
For ϕ meson, A is independent of N_P

- T constant
- no canonical suppression
  $\rightarrow \langle \frac{d\rho}{dy} \rangle_{core} \approx$ constant
- f proportional to $\frac{d\rho_e}{dy}$
  $\rightarrow f \approx$ constant

ϕ yields support geometrical interpretation

ϕ meson very well described in 2-component picture

Difficult to describe in conventional SHM fits



← ϕ/N_P in Au-Au per $\phi/2$ in pp at 200GeV

A can be fixed from data

- blue:A fixed to peripheral
- red: A fixed to central

Strangeness undersaturation in A-A due to corona effects?

- In central C-C, Si-Si, Pb-Pb at top SPS beam energy: strangeness undersaturation ($\gamma_S < 1$) can be understood in two component picture Phys.Rev.C73:044905
- First (very preliminary) fits at RHIC Au-Au 200AGeV: Two component model can describe the data at least at the same level as SHM(γ_S)

4 free parameters $\longrightarrow$ 3 free parameters
Opens room for more complicated corrections

Summary and outlook

Summary

- We confirm (some of the) previous results in Au-Au collisions at RHIC
- Central values of fit parameters from fits to ratios and yields in approximate agreement, χ^2_{min} not!
- Neither centrality nor beam energy dependence in thermodynamical state at RHIC at chemical freeze-out (non-peripheral collisions)
- γ_S might reflect core-corona effects in A-A collisions
- ϕ yields support two-component picture, disfavor SCV picture

Outlook

- Repeat analysis at RHIC in the two-component frame-work