

Equilibration of hadrons in HICs via Hagedorn states

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Motivation

Bootstrap model

covariant formulation, conserved charges (B,S,Q)
detailed balance

Results and Outlook

Implementation into UrQMD / GiBUU

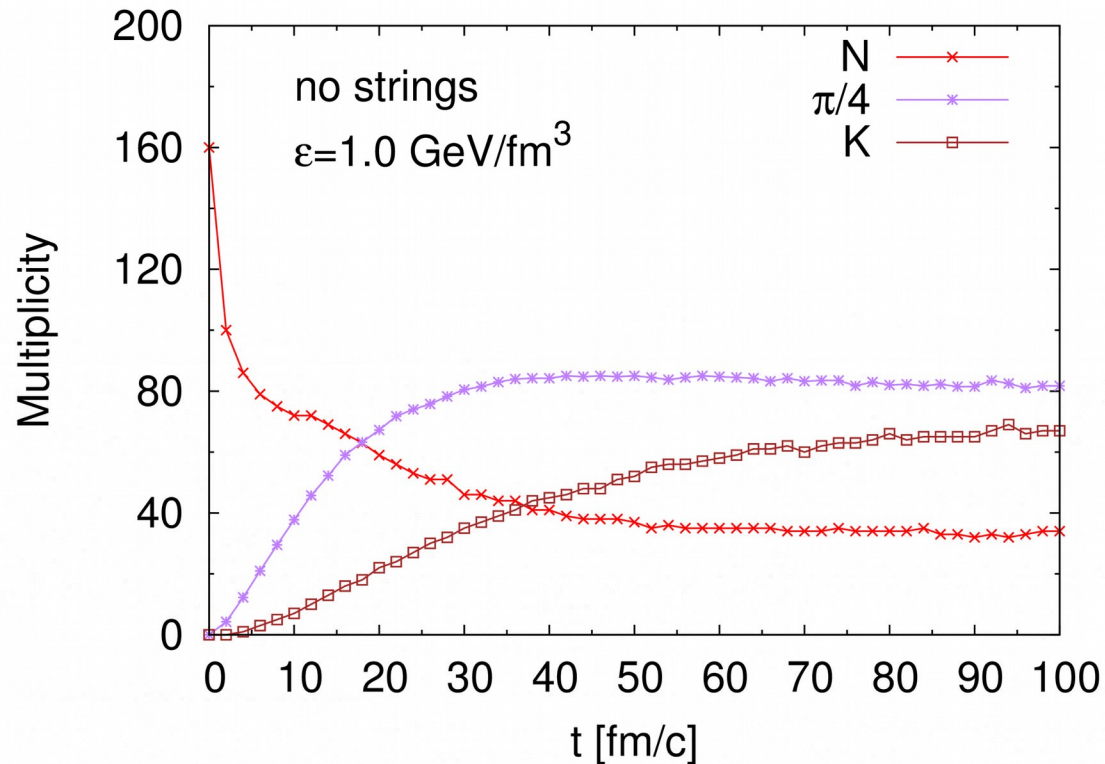
M.Beitel, KG, C.Greiner, PRC 90 (2014) 045203

UrQMD Box

UrQMD: hadronic transport model

Bass et al., Prog.Part.Nucl.Phys. 41 (1998), 255

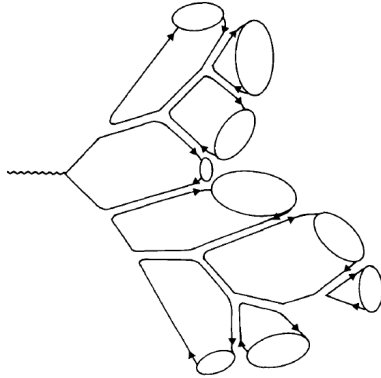
Problem: chemical equilibration takes too long



Colorless Heavy Objects

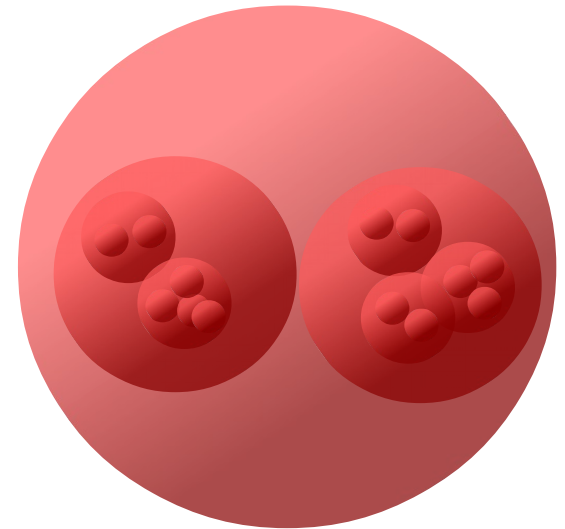
Cluster (HERWIG)

B.Webber, Nucl.Phys.B 238 (1984) 492



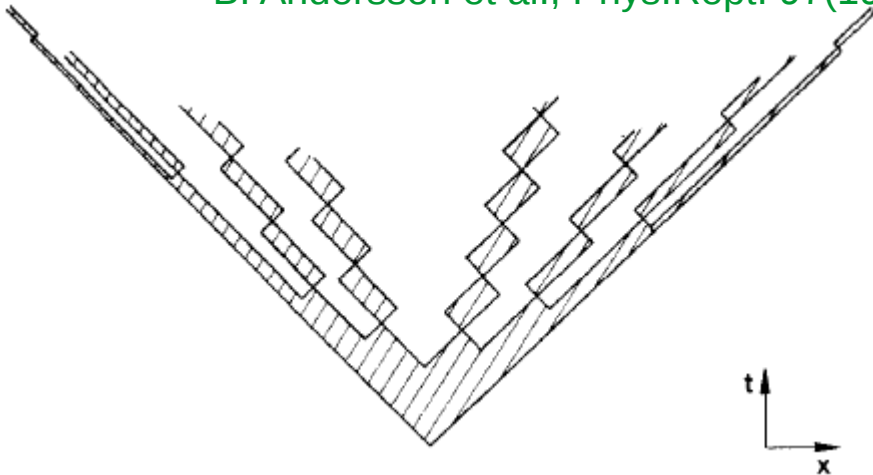
Hagedorn states

R.Hagedorn, Nuovo Cim. Suppl. 3 (1965) 147



Strings (Lund)

B. Andersson et al., Phys.Rept. 97(1983) 31



may interact !

Application of Hagedorn states

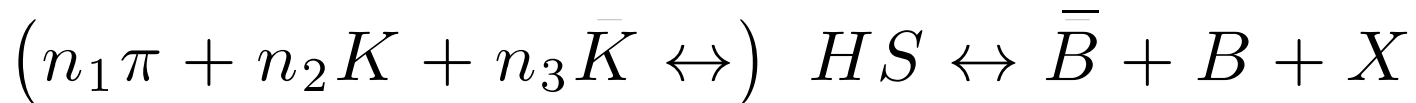
- at SPS energies chem. equilibration time is 1-3 fm/c



C.Greiner, S.Leupold, 2000

- at RHIC energies chem. equilibration time is 10 fm/c
(with same approach)

- **fast** chem. equilibration mechanism through Hagedorn states



- dynamical evolution through set of coupled **rate equations** leads to 5 fm/c for $B\bar{B}$ pairs

J.Noronha-Hostler et al., PRL100 (2008)

J.Noronha-Hostler et al., J.Phys.G 37 (2010)

J.Noronha-Hostler et al., Phys. Rev C81 (2010)

Bootstrap

cf. S. Frautschi, PRD 3 (1971) 2821
C. Hamer, S. Frautschi, PRD 4 (1971) 2125

■ Assumption: only 2-body (detailed balance!)

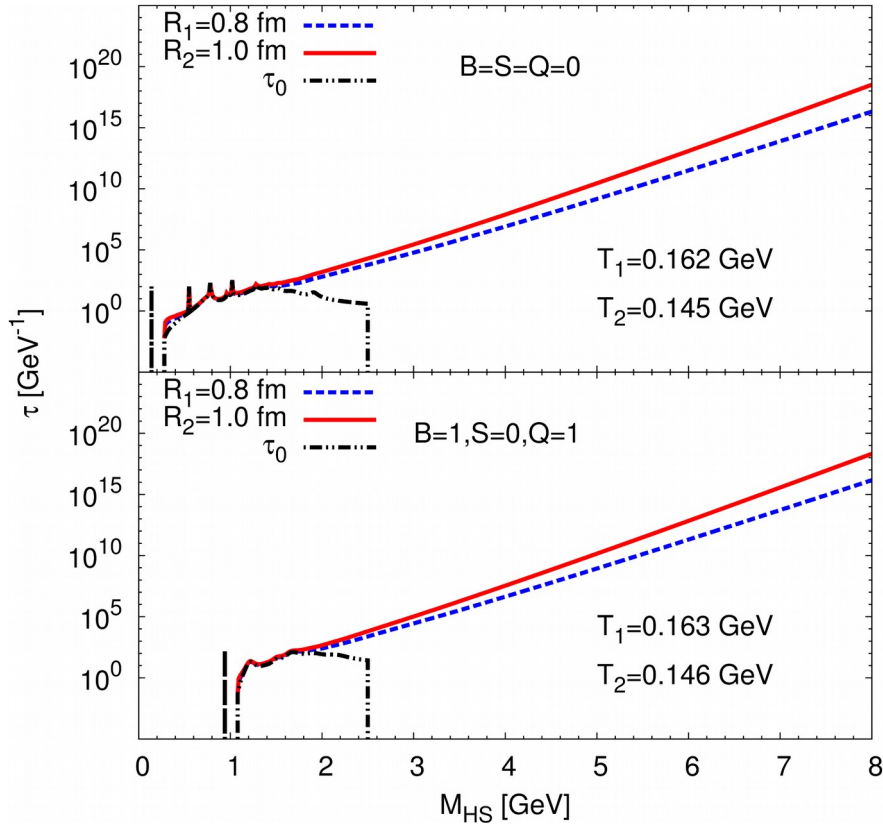
■ Bootstrap equation $\vec{C} = (B, S, Q)$

$$\tau_{\vec{C}}(m) = \frac{R^3}{3\pi m} \sum_{\vec{C}_1, \vec{C}_2} \iint dm_1 dm_2 m_1 \tau_{\vec{C}_1}(m_1) m_2 \tau_{\vec{C}_2}(m_2) \\ \times p_{\text{cm}}(m, m_1, m_2) \delta(\vec{C} - \vec{C}_1 - \vec{C}_2)$$

■ Total decay width (via detailed balance)

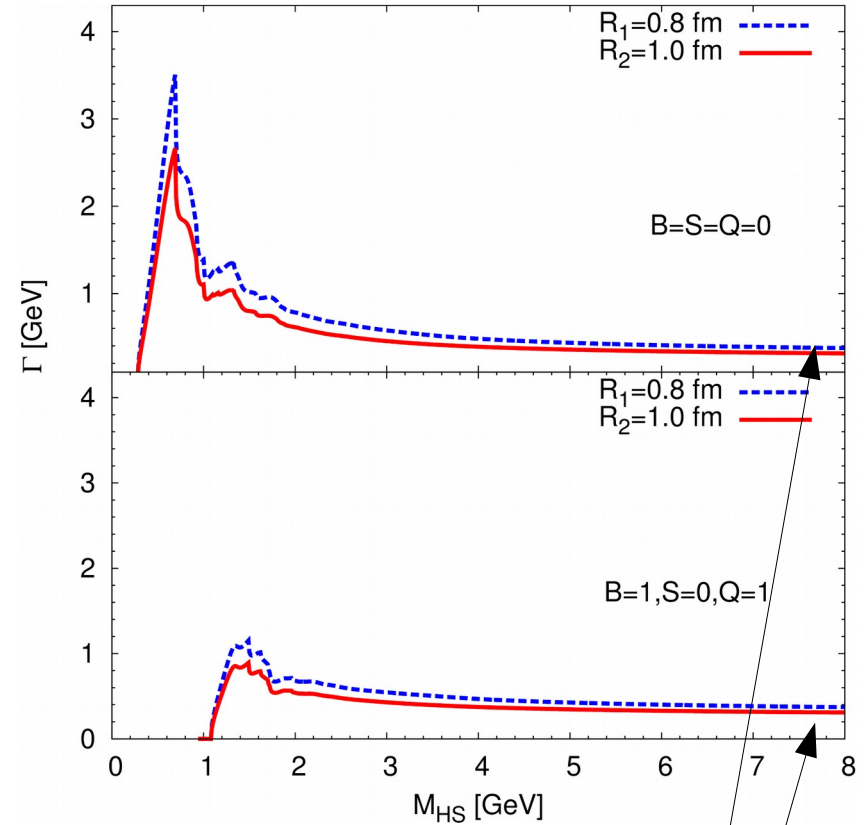
$$\Gamma_{\vec{C}}(m) = \frac{\sigma}{2\pi^2 \tau_{\vec{C}}(m)} \sum_{\vec{C}_1, \vec{C}_2} \iint dm_1 dm_2 \tau_{\vec{C}_1}(m_1) \tau_{\vec{C}_2}(m_2) \\ \times p_{\text{cm}}^2(m, m_1, m_2) \delta(\vec{C} - \vec{C}_1 - \vec{C}_2)$$

Spectra, Width



Radius ↗ : Slope T ↘

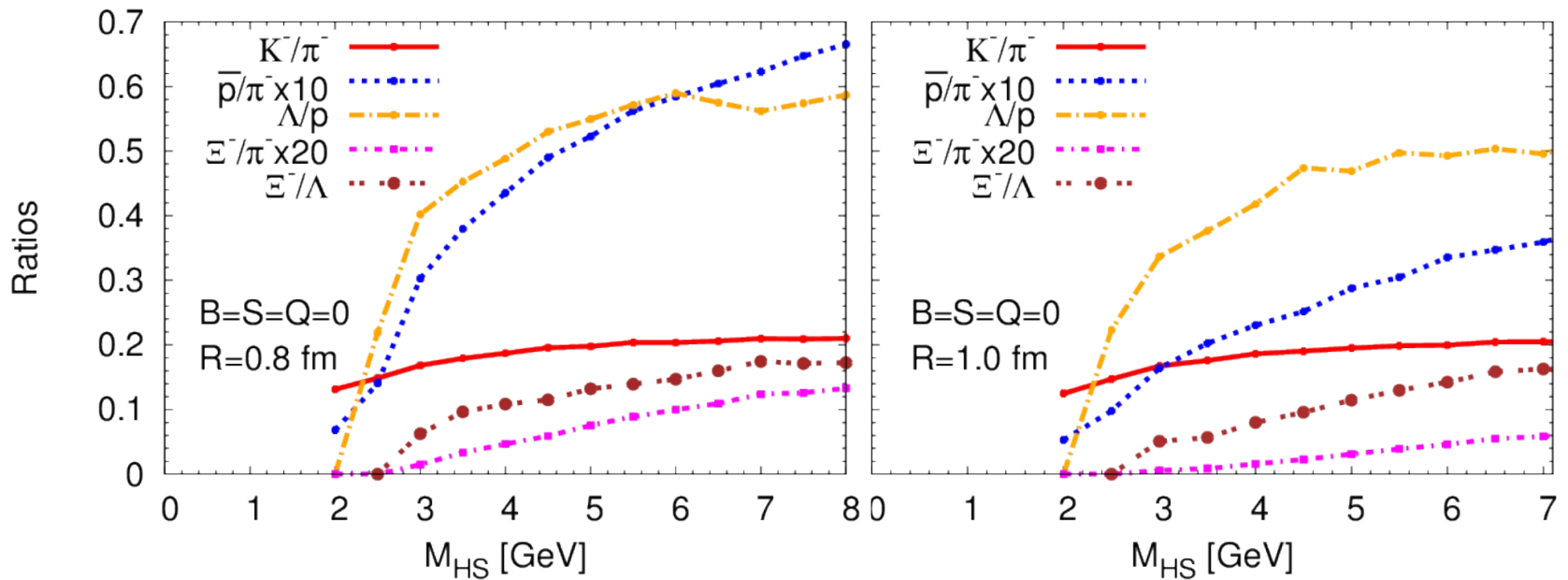
T quite independent of charges



Radius ↗ : Width Γ ↘

nonzero !

Single HS cascading decay: Multiplicity ratios



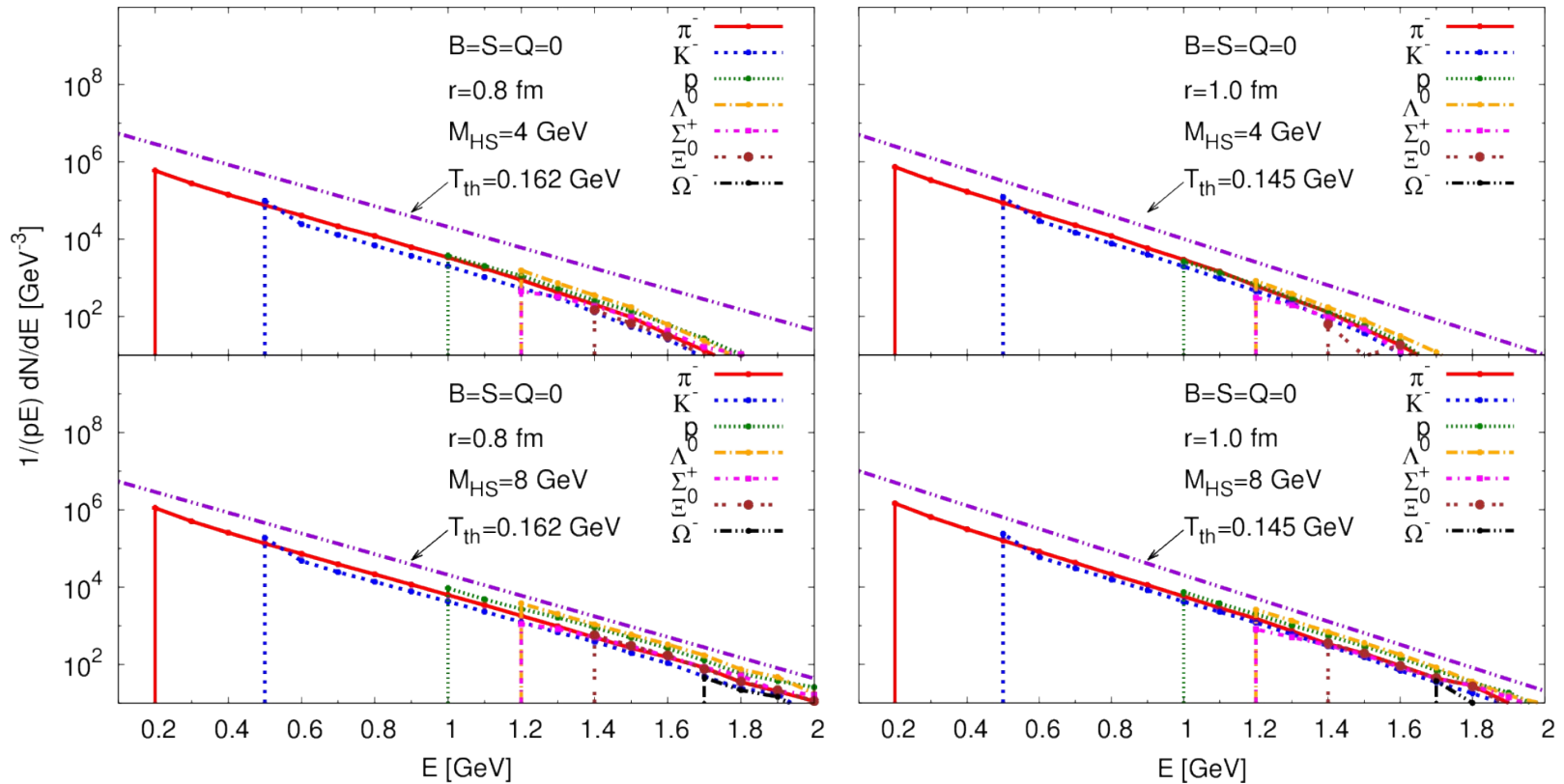
	p-p	Pb-Pb	4 GeV	8 GeV
K^-/π^-	0.123(14)	0.149(16)	0.187	0.210
\bar{p}/π^-	0.053(6)	0.045(5)	0.043	0.066
Λ/π^-	0.032(4)	0.036(5)	0.021	0.038
Λ/\bar{p}	0.608(88)	0.78(12)	0.494	0.579
Ξ^-/π^-	0.003(1)	0.0050(6)	0.0023	0.0066
$\Omega^-/\pi^- \cdot 10^{-3}$	—	0.87(17)	0.086	0.560

data: ALICE @ LHC

p - p : $\sqrt{s_{NN}} = 0.9$ TeV

Pb - Pb : $\sqrt{s_{NN}} = 2.8$ TeV

Single HS cascading decay: Spectra



- spectra of decay products of single HS cascading decay chain are **thermal !!!**
- slope equals Hagedorn temperature
- slope independent of mass, radius, charges

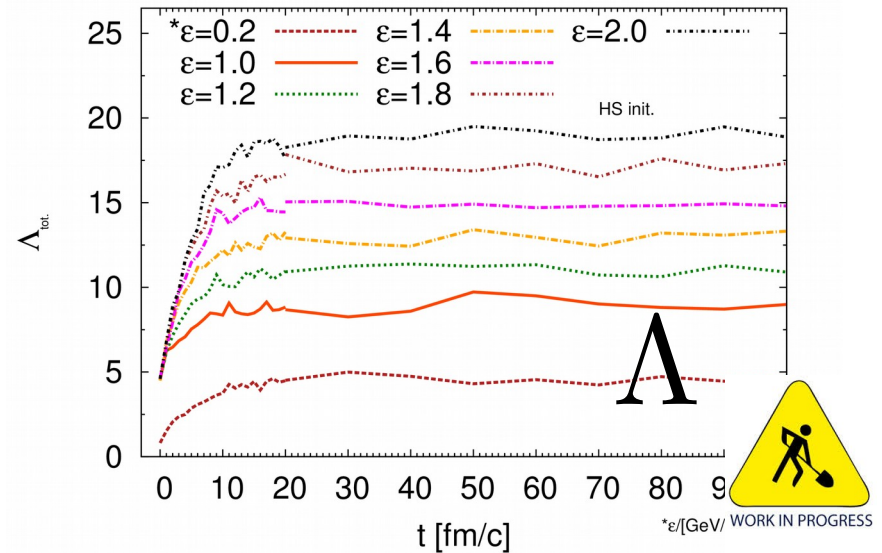
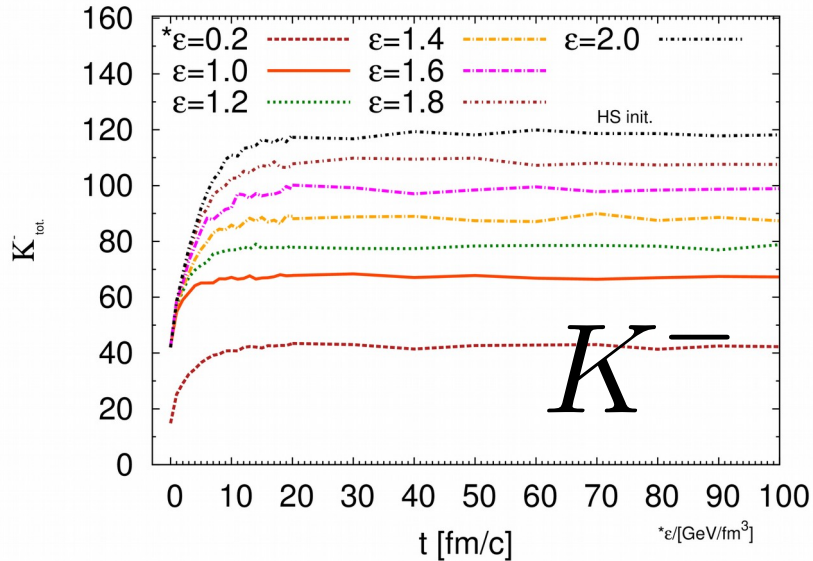
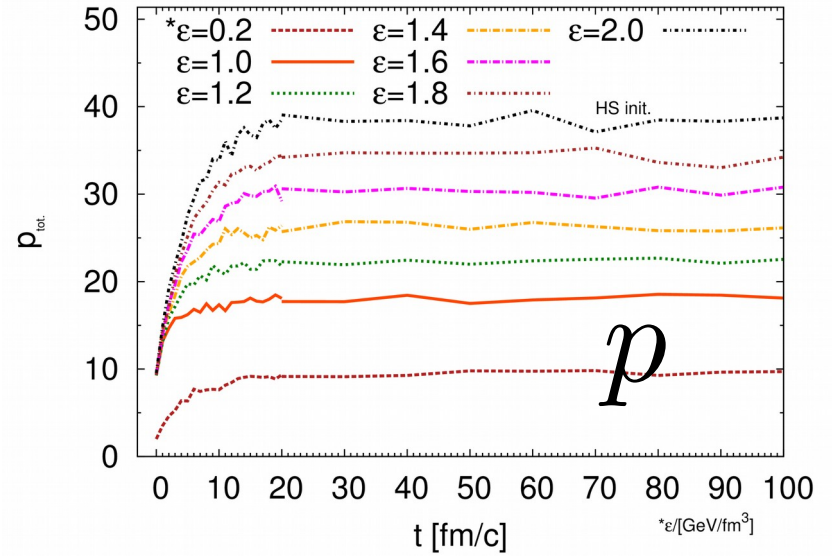
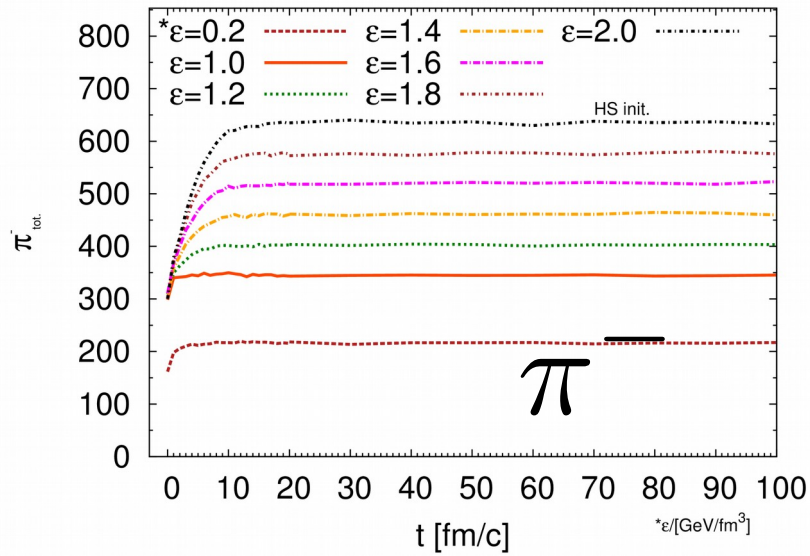
UrQMD Box calculations

- Implementation into UrQMD
 - Creation of Hagedorns replaces string interactions
 - Box calculations
 - Different initialization scenarios
 - Only pions
 - Only hadrons
 - **Only Hagedorn states**
- Bottom-up
- Top-down

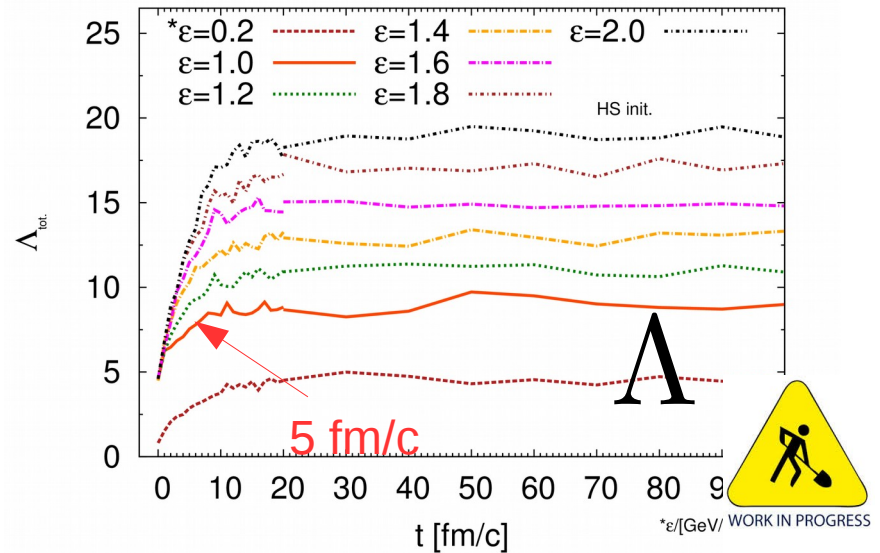
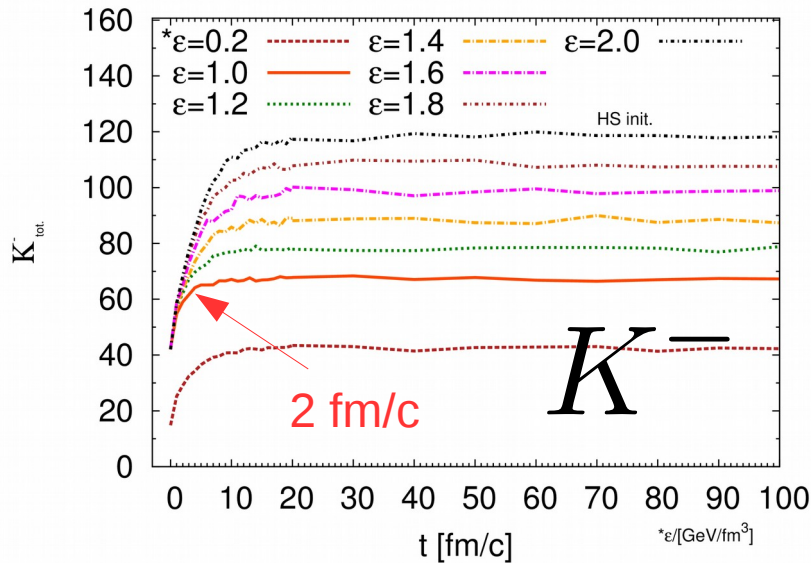
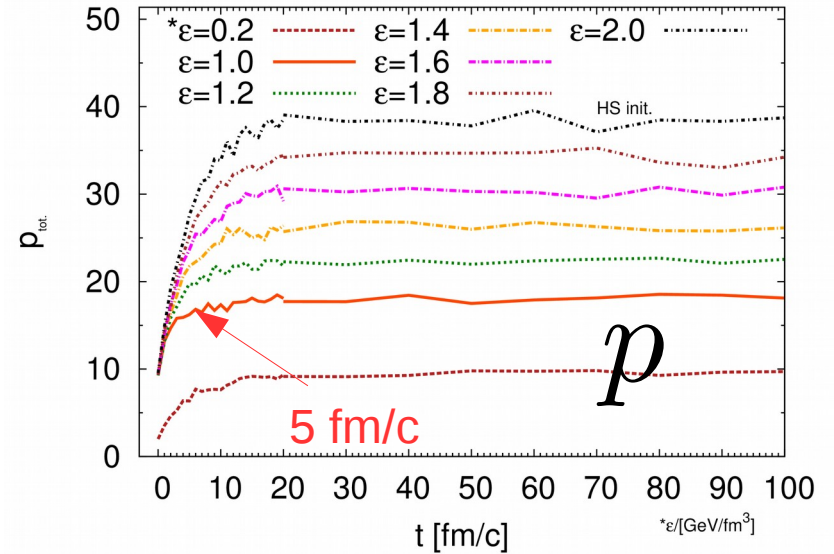
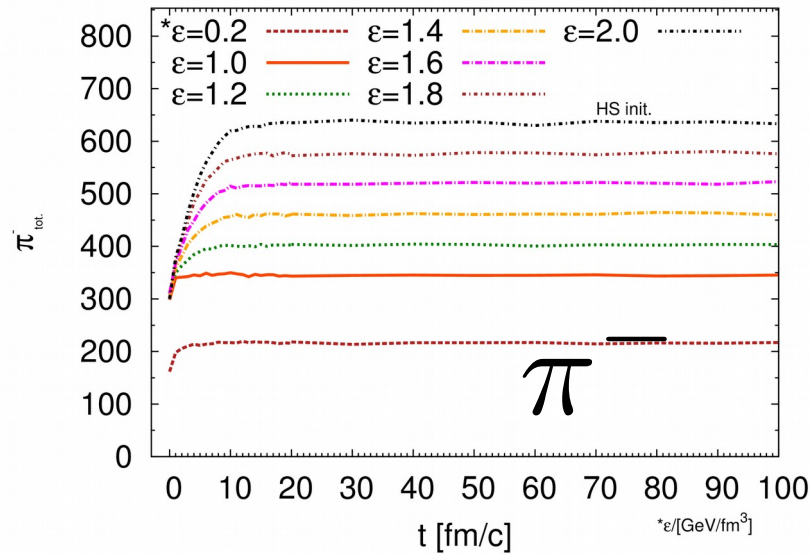


WORK IN PROGRESS

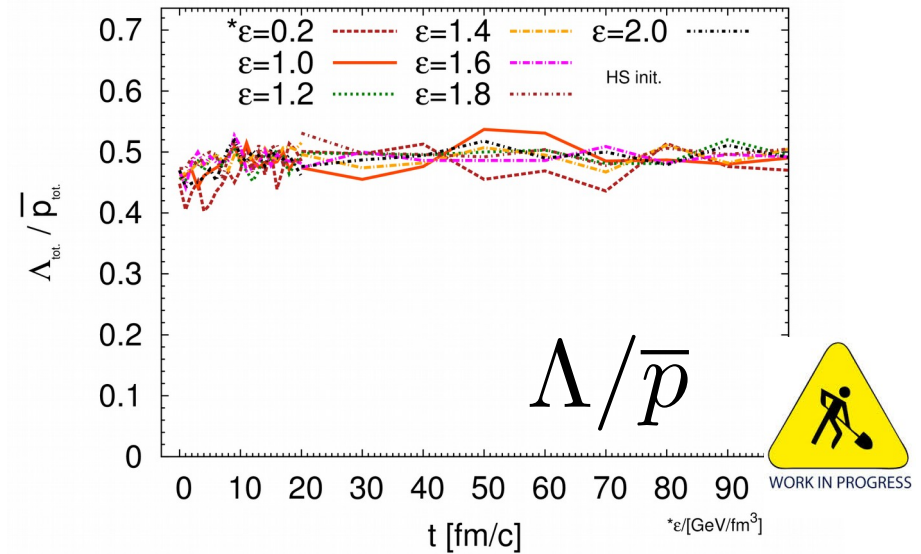
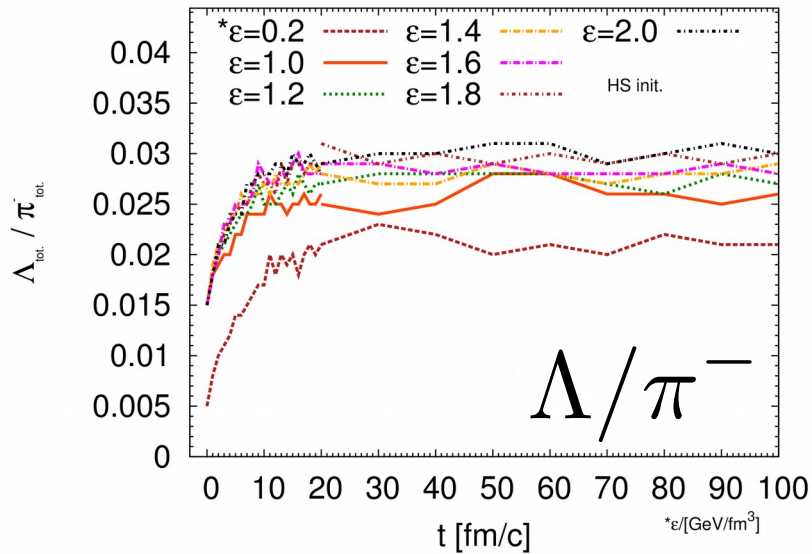
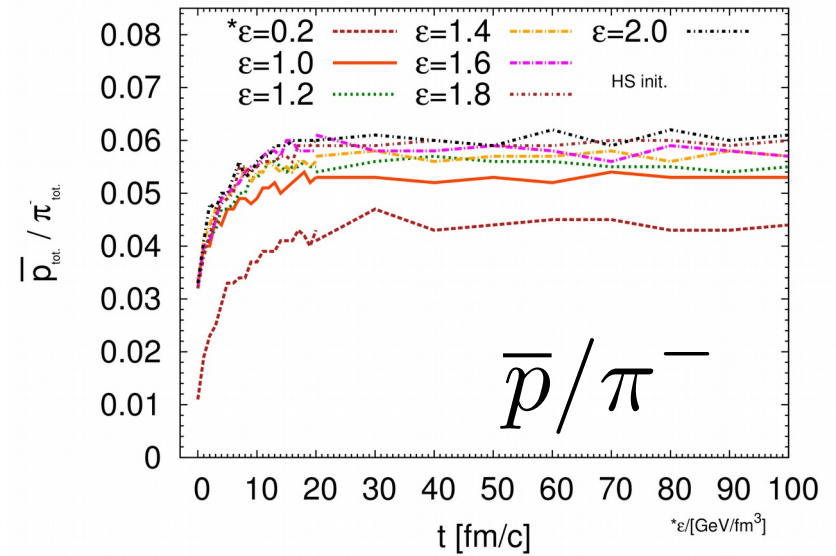
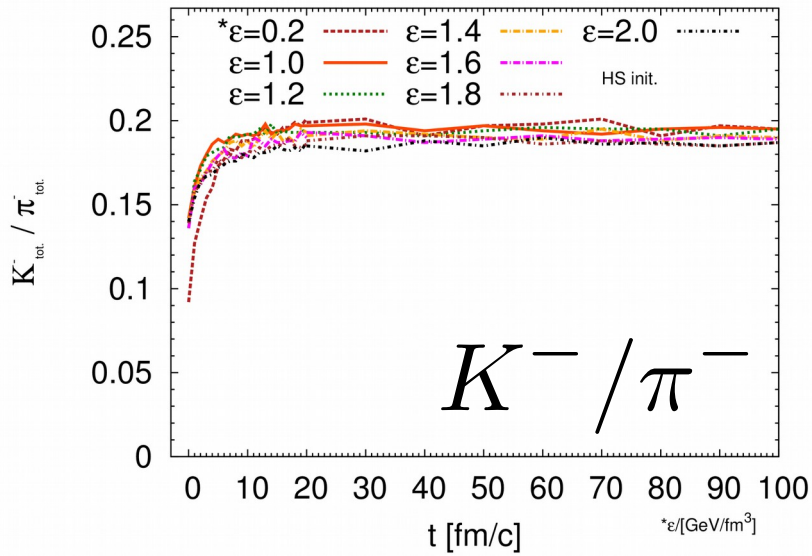
UrQMD-Box, HS init



UrQMD-Box, HS init



UrQMD-Box, HS init



UrQMD-Box, HS init

- Kinetic equilibration, slopes



WORK IN PROGRESS

Conclusions

- Microcanonical bootstrap implementation
- HS properties connected to UrQMD limitations
 - Input 'known hadrons' as implemented in UrQMD
 - Only 2-body processes

- Cascading decay chain of single HS:
 - Multiplicity ratios close to experimental values (ALICE@LHC)
 - Decay product spectra are thermal
 - Slope equals Hagedorn temperature

- Implementation into UrQMD, Box calculations
 - Fast equilibration: 2...5 (...10) fm/c
 - Kinetic slopes = T_H for all $\varepsilon = 0.2...2$ GeV/c

- To be done:
 - Check (B,S,Q) vs. (B,S,I)
 - Implement into GiBUU; cross check!

