Implementation of Hagedorn States into UrQMD

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

Intention

- full integration of Hagedorn States (HS) into UrQMD
- study of the impacts on UrQMD due to HS on:
    - $\frac{\eta}{s}$
    - particle multiplicities
    - chemical equilibration times
    - ...

Hagedorn States

- resonance properties become increasingly uncertain with increasing resonance mass
- Rolf Hagedorn proposed in 1965 that particle number density must grow exponentially with the mass

$$\rho\,(m) \sim \exp\left(\frac{m}{T_H}\right) \qquad (1)$$

- according to the Statistical-Bootstrap-Model near $T_H \approx 0.17$ GeV heavy resonances called Hagedorn States (HS) may become dramatically important
- HS were successfully applied in estimating chemical equilibration times for hyperons at RHIC
- HS are able to explain $\frac{\eta}{s}$ and the speed of sound near T_c

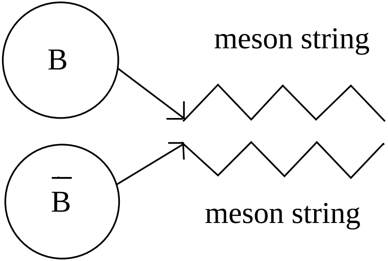
UrQMD

- microscopic Hadron-String Transport model simulating p+p, p+N and A+A collisions in the energy range from Bevalac and SIS up to AGS, SPS and RHIC
- detailed balance is enforced for following processes: meson-baryon, meson-meson, resonance-nucleon and resonance-resonance interaction
- but apart from particle production also string production is possible if total energy of collision participants is high enough
- string cross section is given by

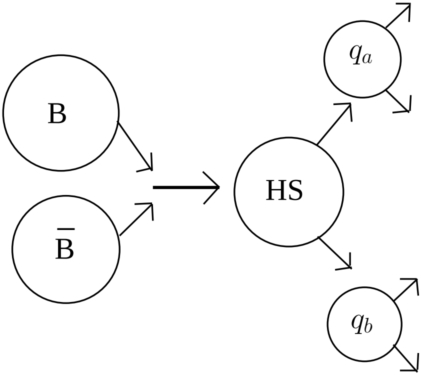
$$\sigma_{string} = \sigma_{tot} - \sigma_{el} - \sum_i \sigma^i_{inel} \tag{2}$$

First aspired changes

strings in UrQMD now



our project: strings $\Rightarrow$ HS



Pal-Danielewicz-approach

- calculation of HS decay width via Pal-Danielewicz-approach
- statistical model for decay and formation of heavy hadronic resonances
- in analogy to low-energy nuclear physics Weisskopf's compound-nucleus model is employed

Modified Hagedorn spectrum

- modified Hagedorn spectrum with charges

$$\rho\left(m,\vec{q}\right)=A\frac{\exp\left[\frac{m-m_g(\vec{q})f(m-m_g(\vec{q}))}{T_H}\right]}{\left[\left\{m-m_g\left(\vec{q}\right)f\left(m-m_g\left(\vec{q}\right)\right)\right\}^2+m_r^2\right]^{\alpha}} \tag{3}$$

$$\left(\vec{q}=\left(B,S,I\right)\right)$$

- spectrum bottom m_g

$$m_g\left(\vec{q}\right)=\alpha_Q\,\mathsf{max}\left(\left|3B+S\right|,2I\right)+\alpha_S\left|S\right| \tag{4}$$

- suppression function decreases the effect of m_g at high m

$$f\left(m-m_g\left(\vec{q}\right)\right)=\frac{1}{1+\left[\frac{m-m_g(\vec{q})}{m_c}\right]^n} \tag{5}$$

Fitting the Hagedorn spectrum

- all known discrete states of specie i with spin J_i and mass m_i

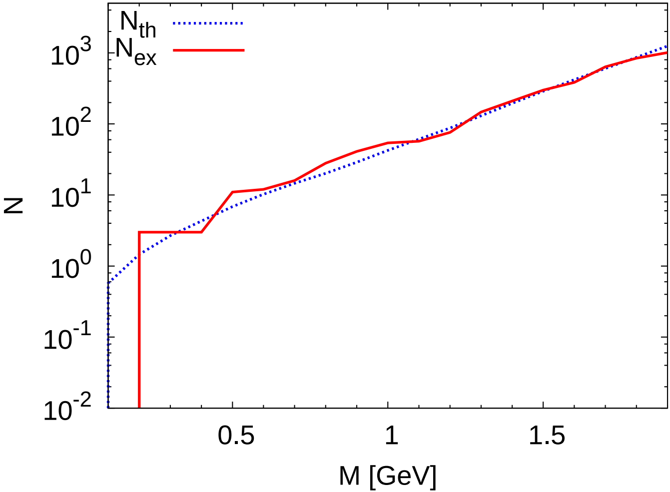
$$N_{ex}(m) = \sum_i (2J_i + 1)\,\Theta(m - m_i) \tag{6}$$

- Hagedorn hypothesis of a continous particle density at different $\vec{q}$

$$N_{th}(m) = \sum_q \int_{m_g(\vec{q})}^{m} \mathrm{d}m' \rho(m', \vec{q}) \tag{7}$$

- minimizing of $\chi^2(N_{ex}, N_{th})$ $(MINUIT)$ gives A and α
- final parameter set used reads:
  - α_Q=0.387 GeV
  - α_S=0.459 GeV
  - m_c=1.8 GeV
  - T_H=0.17 GeV
  - α=1.95
  - A=0.29

Theoretical and experimental cumulants



Cross sections

- formation cross section of a resonance q (h or HS) by following interactions: $q_a + q_b$, $q_a + q_b$, $q_a + q_b$ ($q_i \cong h$, $q_i \cong HS$, $q_i \cong h$ or HS)
- we enforce detailed balance between decay and formation of the resonance q so $|M_{q_a+q_b \to q}|^2 = |M_{q \to q_a+q_b}|^2$
- general cross section

$$\sigma\left(q_a + q_b \to q\right) = \frac{2\,\pi\, m_a\, m_b}{m\, p^*\left(m_a, m_b\right)} \rho\left(m, \vec{q}\right) |M_{q_a+q_b \to q}|^2 \quad (8)$$

- geometrical cross section

$$\sigma\left(q_a + q_b \to q\right) = \langle I^a\, I_3^a\, I^b\, I_3^b \,|\, I\, I_3\rangle^2\, \pi\, R^2 \quad (9)$$

- radius R of HS with r_0=1 fm and m_d=1 GeV is defined as:

$$R\left(m\right) = r_0 \left(\frac{m}{m_d}\right)^{\frac{1}{3}} \quad (10)$$

General expression and decay mode (i)

- general expression for partial decay width of resonance q into the daughters q_a and q_b

$$\Gamma\left(q \rightarrow q_a + q_b\right) = \int \frac{\mathrm{d}\,\vec{p}}{(2\pi)^3} \int \mathrm{d}m'_a \frac{\rho\left(m'_a, \vec{q}_a\right)}{e_a\left(\vec{p}\right)} \int \mathrm{d}m'_b \frac{\rho\left(m'_b, \vec{q}_b\right)}{e_b\left(\vec{p}\right)} \times \quad (11)$$

$$\left|M_{q\rightarrow q_a+q_b}\right|^2 2\pi\delta\left(e_a\left(\vec{p}\right) + e_b\left(\vec{p}\right) - m\right)$$

- first binary decay mode (i) concerns a HS-decay into two hadrons with particle density $\rho_i\left(m'_i\right) = \left(2J_i + 1\right)\delta\left(m'_i - m_i\right)$:

$$\Gamma^{(i)}\left(q \rightarrow q_a + q_b\right) = \langle I^a\, I_3^a\, I^b\, I_3^b \mid I\, I_3\rangle^2 \times \quad (12)$$

$$\frac{\left(2J_a + 1\right)\left(2J_b + 1\right) p^*\left(m_a, m_b\right) R^2}{2\pi\rho\left(m, \vec{q}\right)}$$

Decay modes (ii) and (iii)

- second binary decay mode (ii) concerns a HS-decay into a hadron q_a and a HS q_b

$$\Gamma^{(ii)}\left(q \rightarrow q_a + q_b\right) = \langle I^a\, I_3^a\, I^b\, I_3^b \mid I\, I_3\rangle^2 \times \qquad (13)$$

$$\frac{(2J_a+1)\, mR^2}{2\pi\rho\left(m,\vec{q}\right)} \int\limits_0^{p^*(m_a,m_b)} \mathrm{d}p\, p^3 \frac{\rho\left(\sqrt{m^2+m_2^2-2me_a}, \vec{q}_a\right)}{e_a\sqrt{m^2+m_a^2-2me_a}}$$

- third binary decay mode (iii) concerns a HS-decay into two HSs.

$$\Gamma^{(iii)}\left(q \rightarrow q_a + q_b\right) = \langle I^a\, I_3^a\, I^b\, I_3^b \mid I\, I_3\rangle^2 \times \qquad (14)$$

$$\frac{R^2}{2\pi\rho\left(m,\vec{q}\right)} \int\limits_{m_a^c}^{m-m_b^c} \mathrm{d}m_a' \int\limits_{m_b^c}^{m-m_a} \mathrm{d}m_b'\, p^*\left(m_a', m_b'\right) \rho\left(m_a', \vec{q}_a\right) \rho\left(m_b', \vec{q}_b\right)$$

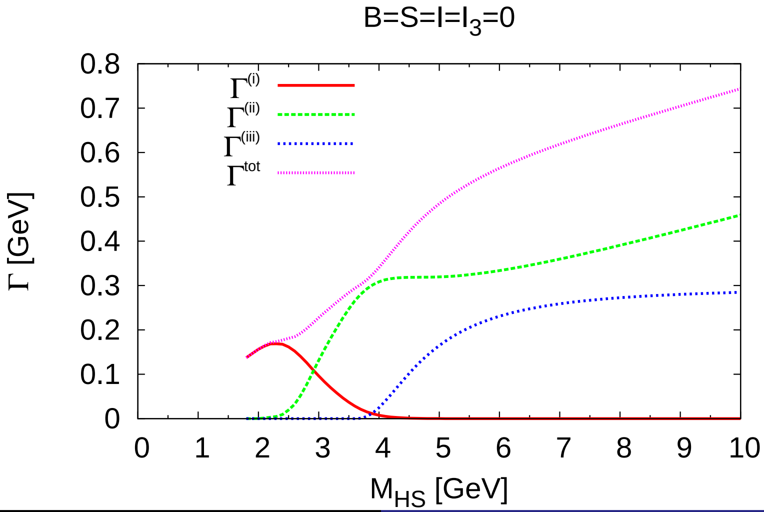
$$\left(m_i^c = \max\left[m_c, m_g\left(\vec{q}_i\right)\right]\right)$$

Total decay width

- total decay width $\Gamma\left(m, \vec{q}\right)$ is the sum over all decay channels where B,S and I are conserved exactly

$$\Gamma\left(m, \vec{q}\right) = \sum_{\vec{q}_a, \vec{q}_b} \Gamma^{(i)}\left(q \rightarrow q_a + q_b\right) + \sum_{\vec{q}_a, \vec{q}_b} \Gamma^{(ii)}\left(q \rightarrow q_a + q_b\right) + \sum_{\vec{q}_a, \vec{q}_b} \Gamma^{(iii)}\left(q \rightarrow q_a + q_b\right) \tag{15}$$

Decay widths for charge-neutral HS

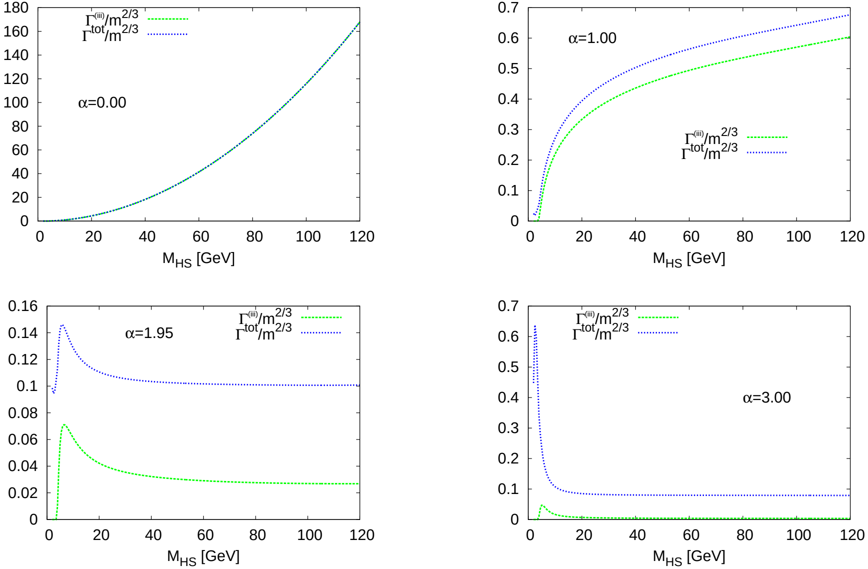


Conclusion

- replacement of strings in UrQMD by HS
- HS creations in secondary collisions like b-$\bar{b}$ as first step
- presentation of a decay width model of HS

THANK YOU FOR YOUR ATTENTION!

Appendix



Γ(iii)tot/m2/3
Γtot/m2/3
α=0.00
α=1.00
α=1.95
α=3.00
MHS [GeV]
0 20 40 60 80 100 120
0 20 40 60 80 100 120 140 160 180
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16