Strangeness Production in Low Energy Heavy Ion Collisions via Hagedorn Resonances

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Hagedorn States

- Motivation, Bootstrap, Detailed Balance
- Strangeness Suppression Factor

Phase Diagram

- Hagedorn States at finite μ_B

arXiv:1712.04018

HADES: phi/K^- ratio

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Bundesministerium für Bildung und Forschung

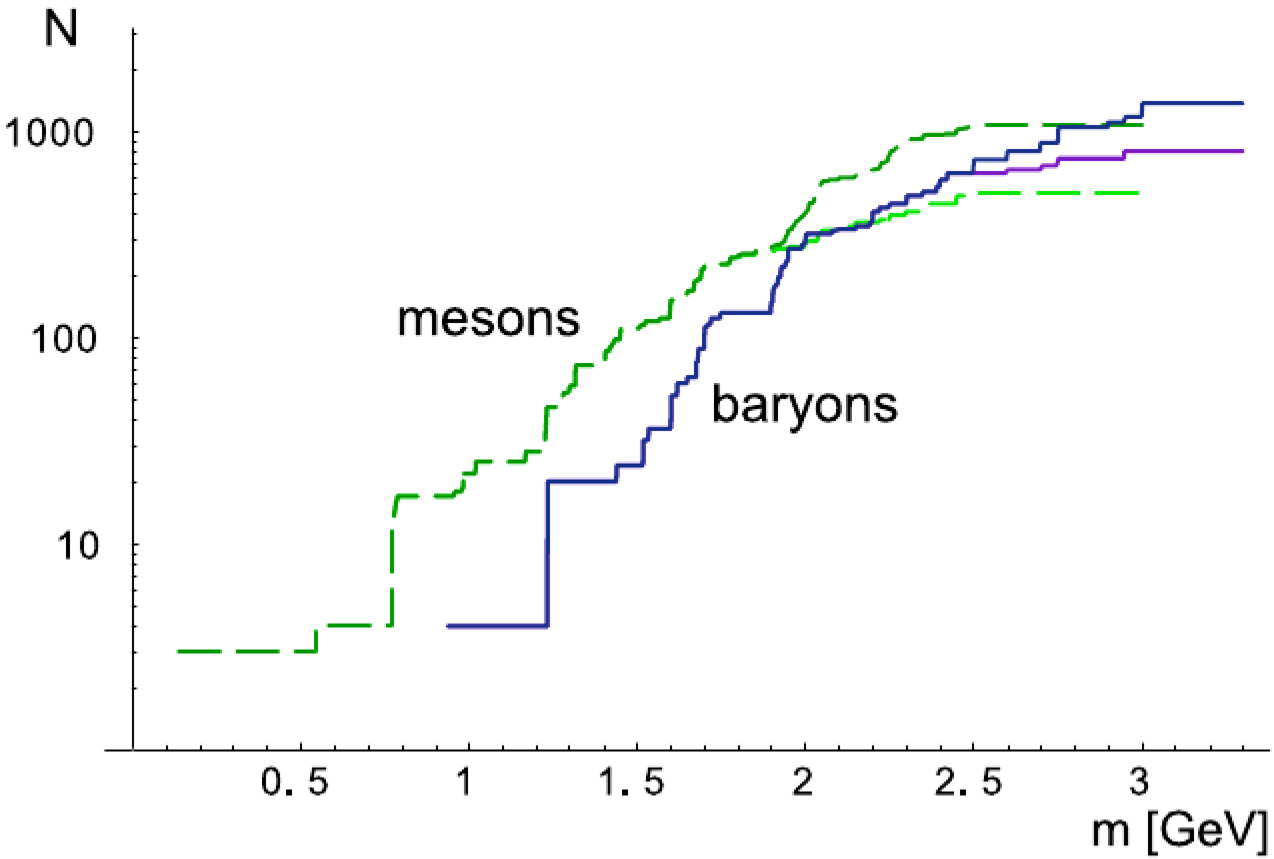
CRC-TR 211 Transport Meeting

Frankfurt, 18.1.2018

Hadronic states

- accumulated spectrum of PDG states

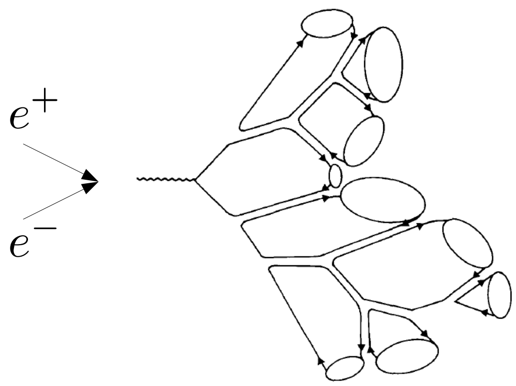
W.Broniowski, W.Florkowski, L.Glozman, PRD 70 (2004) 117503



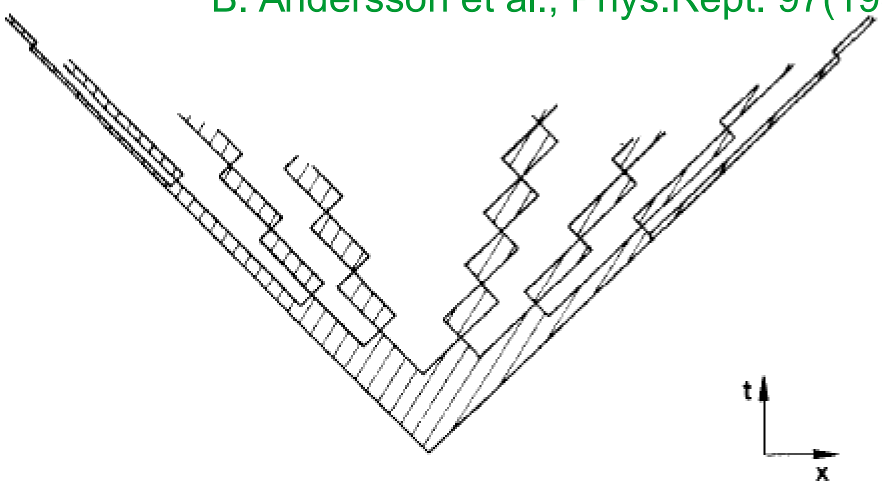
higher masses???

Colorless Heavy Objects

- Cluster (HERWIG)
  B. Webber, Nucl.Phys.B 238 (1984) 492

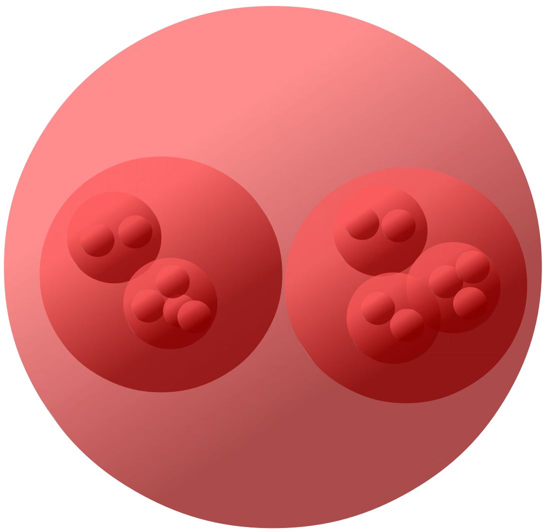


- Strings (Lund)
  B. Andersson et al., Phys.Rept. 97(1983) 31



- Hagedorn states

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



allow for
decay & recombination !!!

Application of Hagedorn states

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

$$\mathrm{n}_1 \pi + n_2 K \leftrightarrow \bar{Y} + p$$

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

$$\left(n_1 \pi + n_2 K + n_3 \bar{K} \leftrightarrow\right) \; HS \leftrightarrow \bar{B} + B + X$$

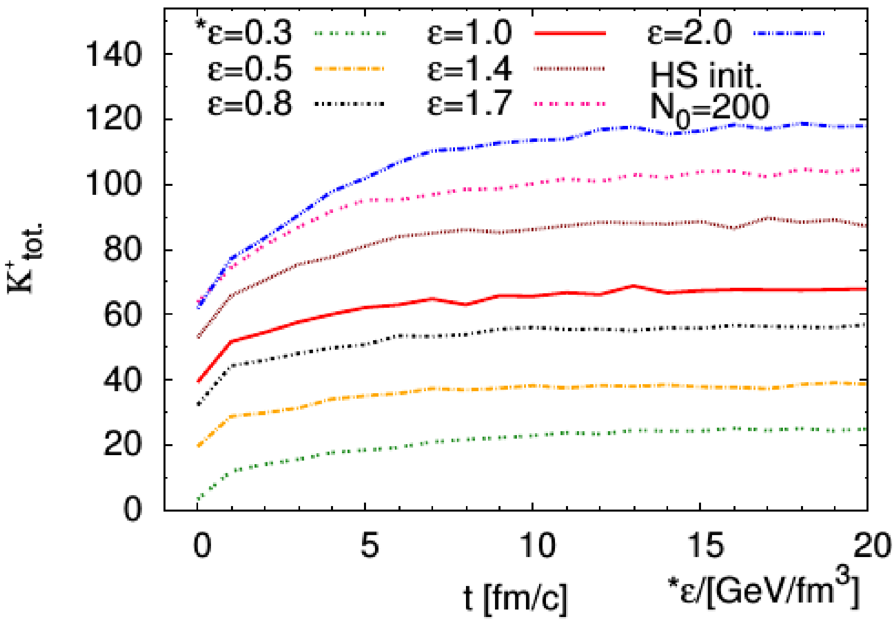
- dynamical evolution through set of coupled rate equations leads to 5 fm/c for B$\bar{\mathrm{B}}$ pairs

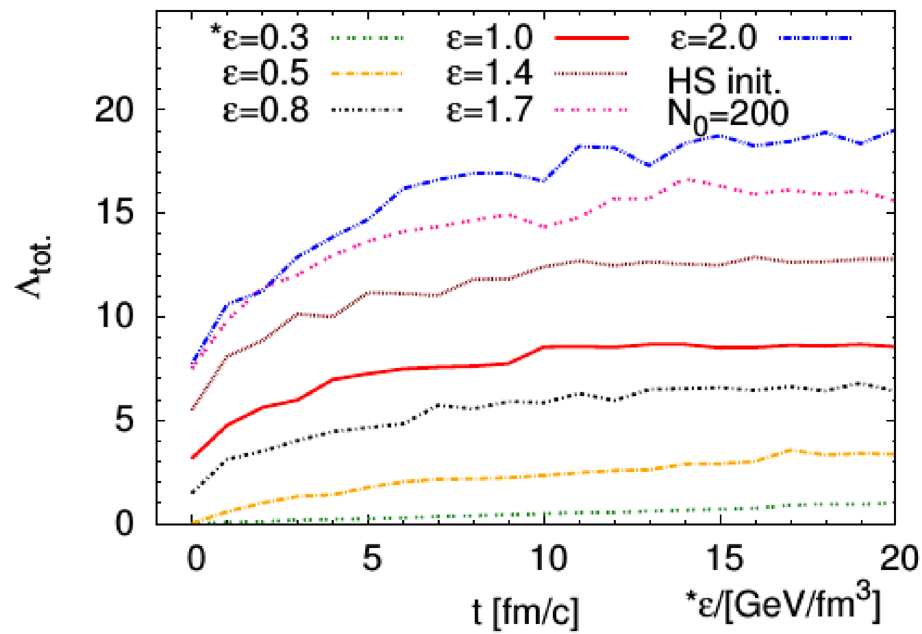
J.Noronha-Hostler et al., PRL100 (2008)
J.Noronha-Hostler et al., J.Phys.G 37 (2010)
J.Noronha-Hostler et al., Phys. Rev C81 (2010)

Application of Hagedorn states

- Dynamical Box calculations within UrQMD

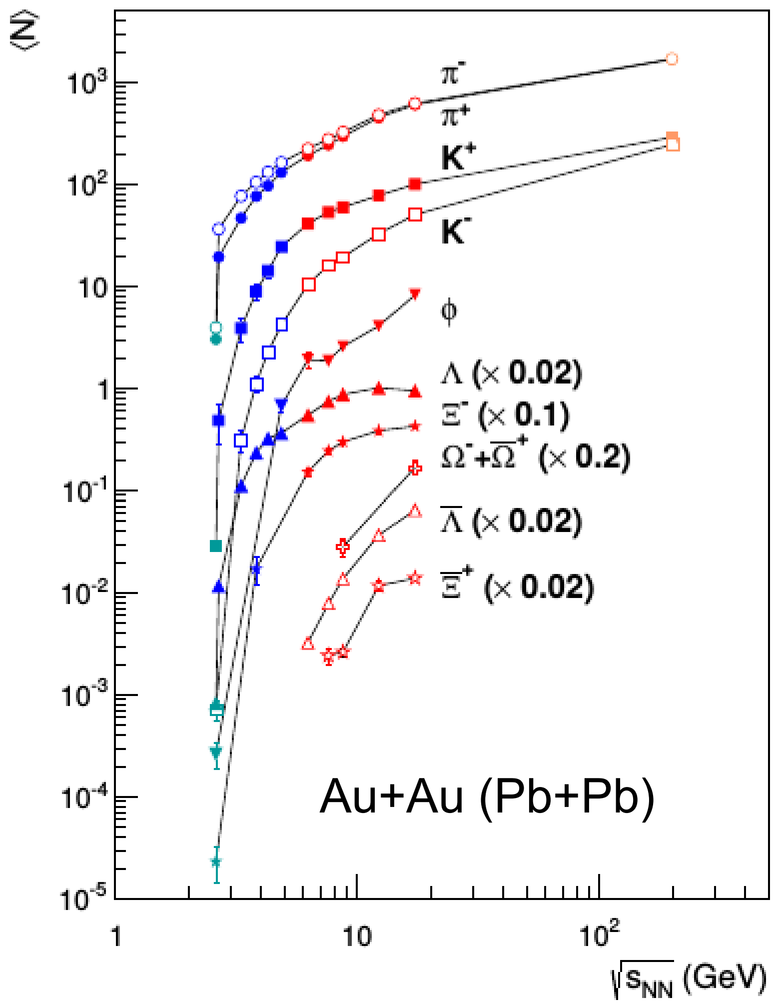
M.Beitel, PhD, 2016





- equilibration time ~5 fm/c

Strangeness at Threshold



H.Schuldes, PhD, 2016

Blume, Markert, Prog.Part.Nucl.Ph 66(2011) 834

Threshold

	$\sqrt{s_{\mathrm{thr}}}$
$NN \rightarrow NK^+\Lambda$	2.55 GeV
$NN \rightarrow NNK^+K^-$	2.87 GeV
$NN \rightarrow NN\phi$	2.89 GeV
Au(1.23 AGeV)Au:	2.41 GeV

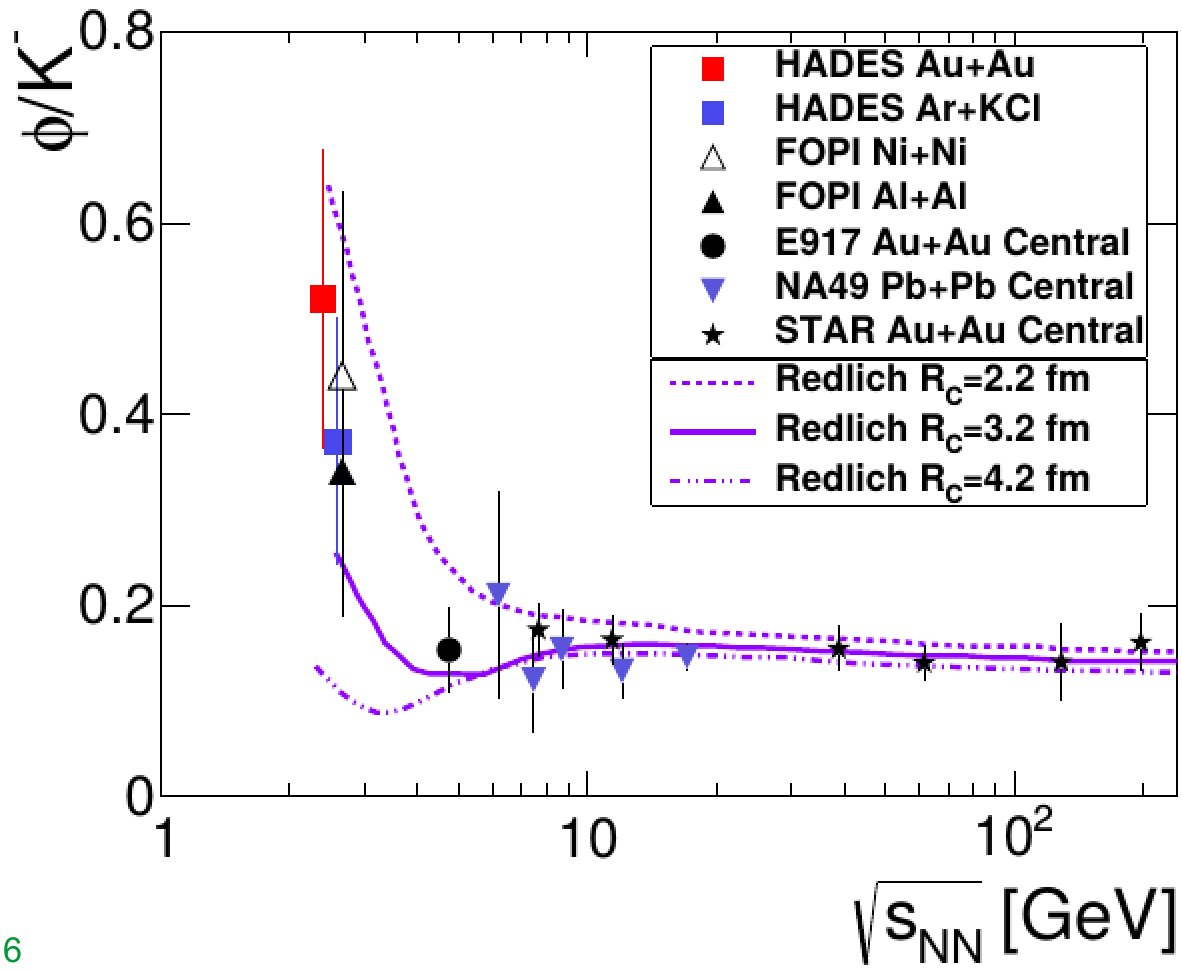
Transport

- $NN \rightarrow N\Delta$ $\quad N\Delta \rightarrow NK^+Y$

  $NN \rightarrow NN\pi$ $\quad N\pi \rightarrow K^+Y$
- $Y\pi \leftrightarrow NK^-$
- $BB \rightarrow BB\phi$ $\quad B\pi \rightarrow B\phi$

phi/K-

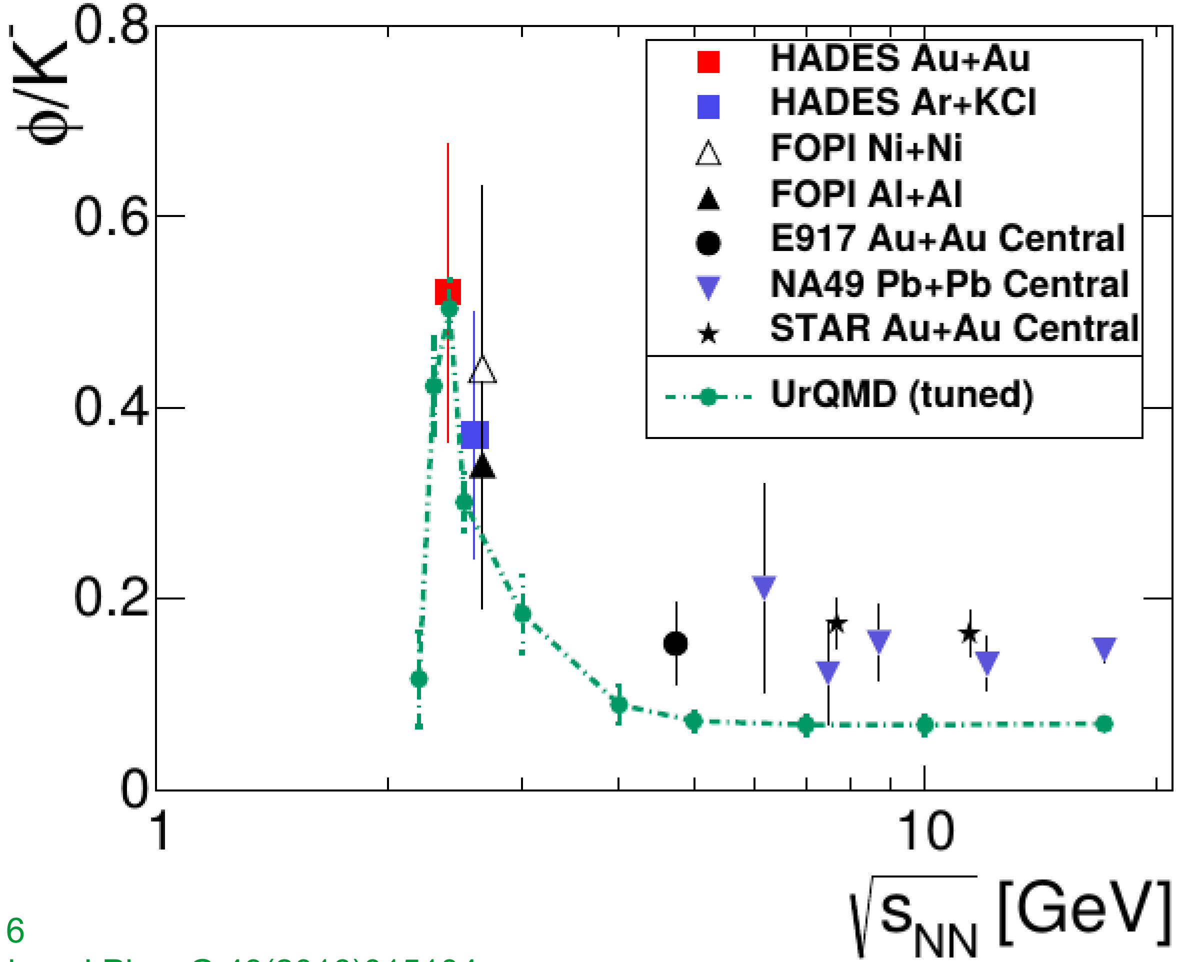
- statistical hadronisation, canonical strangeness suppression



H.Schuldes, PhD, 2016

phi/K-

- UrQMD + higher N* resonances $N^* \to N\phi$



H.Schuldes, PhD, 2016
J.Steinheimer, M.Bleicher, J.Phys.G 43(2016)015104

Hagedorn Bootstrap

cf.: S. Frautschi, PRD 3 (1971) 2821
C. Hamer, S. Frautschi, PRD 4 (1971) 2125
J. Yellin, NPB 52 (1973) 583

- Assumption: only 2-body (detailed balance!)
- Input: known hadrons (UrQMD/GiBUU/PDG)

- Bootstrap equation

$\vec{C} = \text{quantum numbers}$

$$\tau_{\vec{C}}(m) = \tau^0_{\vec{C}}(m) + \frac{V(m)}{(2\pi)^2\, 2m} \sum_{\vec{C}_1,\vec{C}_2}^{*} \iint \mathrm{d}m_1 \mathrm{d}m_2$$

$$\times \;\; \tau_{\vec{C}_1}(m_1)\, \tau_{\vec{C}_2}(m_2)\, m_1\, m_2\; p_{\rm cm}(m, m_1, m_2)$$

non-linear integral equation, Volterra type

Hagedorn Bootstrap

- Quantum number conservation

$$\sum_{\vec{C}_1,\vec{C}_2}^{*} = \sum_{\vec{C}_1,\vec{C}_2} \delta(\vec{C};\, \vec{C}_1, \vec{C}_2)$$

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

$$\vec{C} = (B, S, I)$$

$$\delta(\vec{C};\, \vec{C}_1, \vec{C}_2) = \delta(C^a;\, C_1^a, C_2^a)\, \delta(C^b;\, C_1^b, C_2^b) \cdots$$

- additive, discrete: B,S,Q, …

$$\delta(X; X_1, X_2) = \delta_{X, X_1 + X_2}$$

- non-additive: I

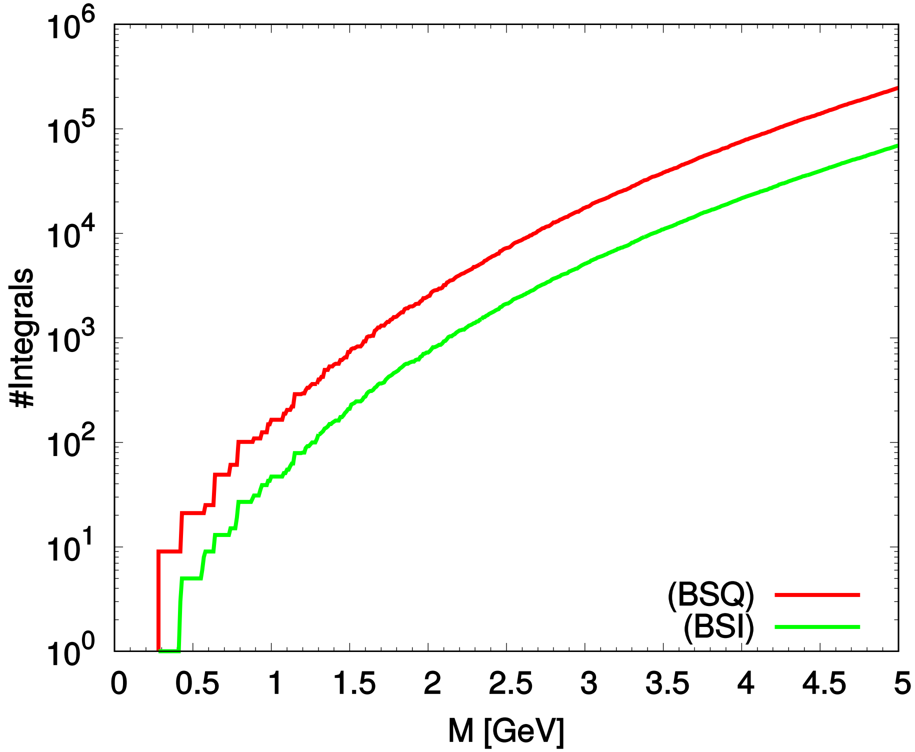
$$\delta(I; I_1, I_2) = \begin{cases} 1 & \exists I^z, I_1^z, I_2^z : \langle I_1 I_1^z; I_2 I_2^z | I I^z \rangle \neq 0 \\ 0 & \text{otherwise} \end{cases}$$

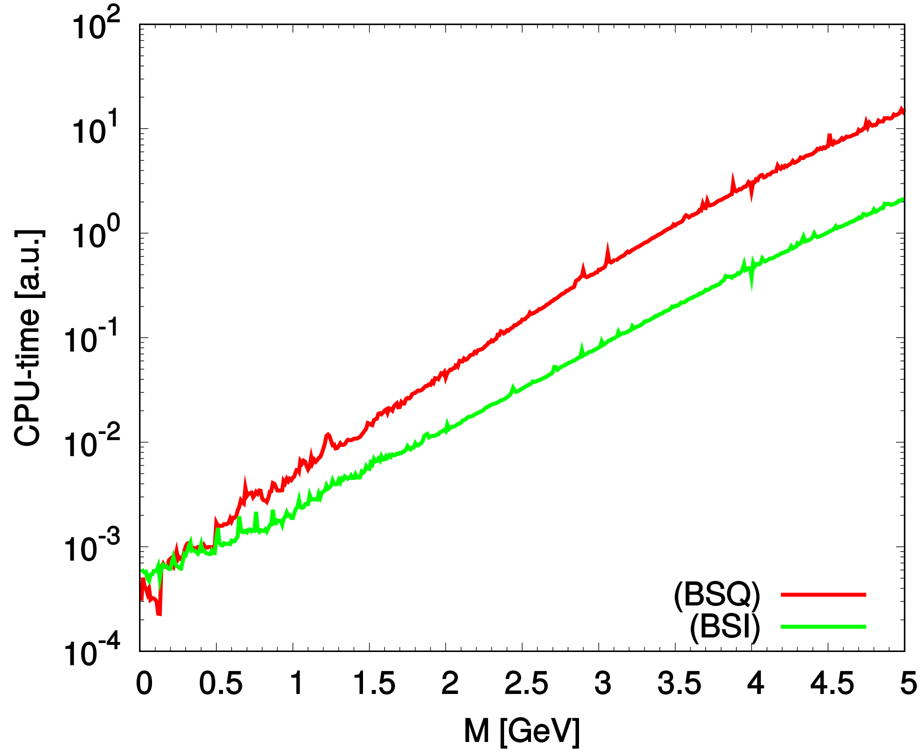
Gell-Mann-Nishijima formula: $2I_z = 2Q - B - S$

Hagedorn Bootstrap

- (B,S,Q) or (B,S,I) ?
  - Physics the same
  - (B,S,I) is faster: less integrals to solve, ‚faster‘ integrals

naive: 2x3 pions = 9 charge combinations, 3 isospin combinations
optimized: 9 integrals 1 integral





Hagedorn Total Decay Width

- Total Decay Width (via Detailed Balance)

$$\left|\mathcal{M}_{2\to 1}\right|^2 = \left|\mathcal{M}_{1\to 2}\right|^2$$

$$\Gamma_{\vec{C}}(m) = \frac{\sigma(m)}{(2\pi)^2} \frac{1}{\tau_{\vec{C}}(m) - \tau^0_{\vec{C}}(m)} \sum_{\vec{C}_1,\vec{C}_2}^{*} \iint \mathrm{d}m_1 \mathrm{d}m_2 \times \tau_{\vec{C}_1}(m_1)\,\tau_{\vec{C}_2}(m_2)\; p^2_{\mathrm{cm}}(m, m_1, m_2)$$

- Model input

$$V(m) = V = \frac{4}{3}\pi R^3$$

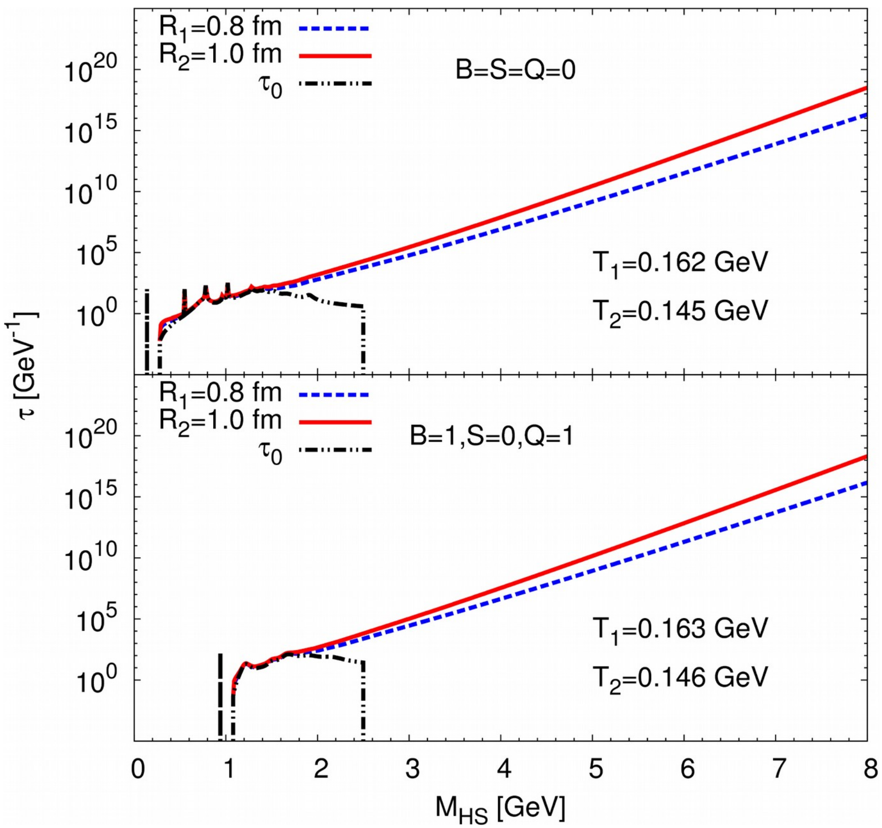
$$\sigma(m) = \sigma = \pi R^2$$

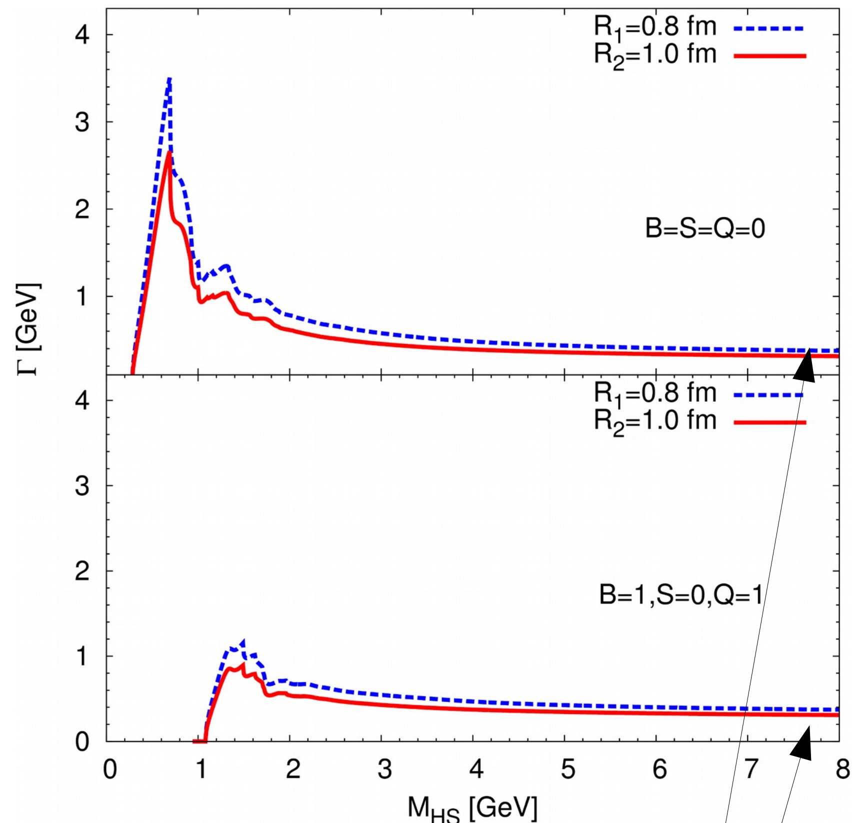
$R \sim 1\,\mathrm{fm}$

$\sigma \sim 30\,\mathrm{mb}$

$T_H \sim 160\,\mathrm{MeV}$

Spectra, Width





Radius ↗ : Slope T ↘

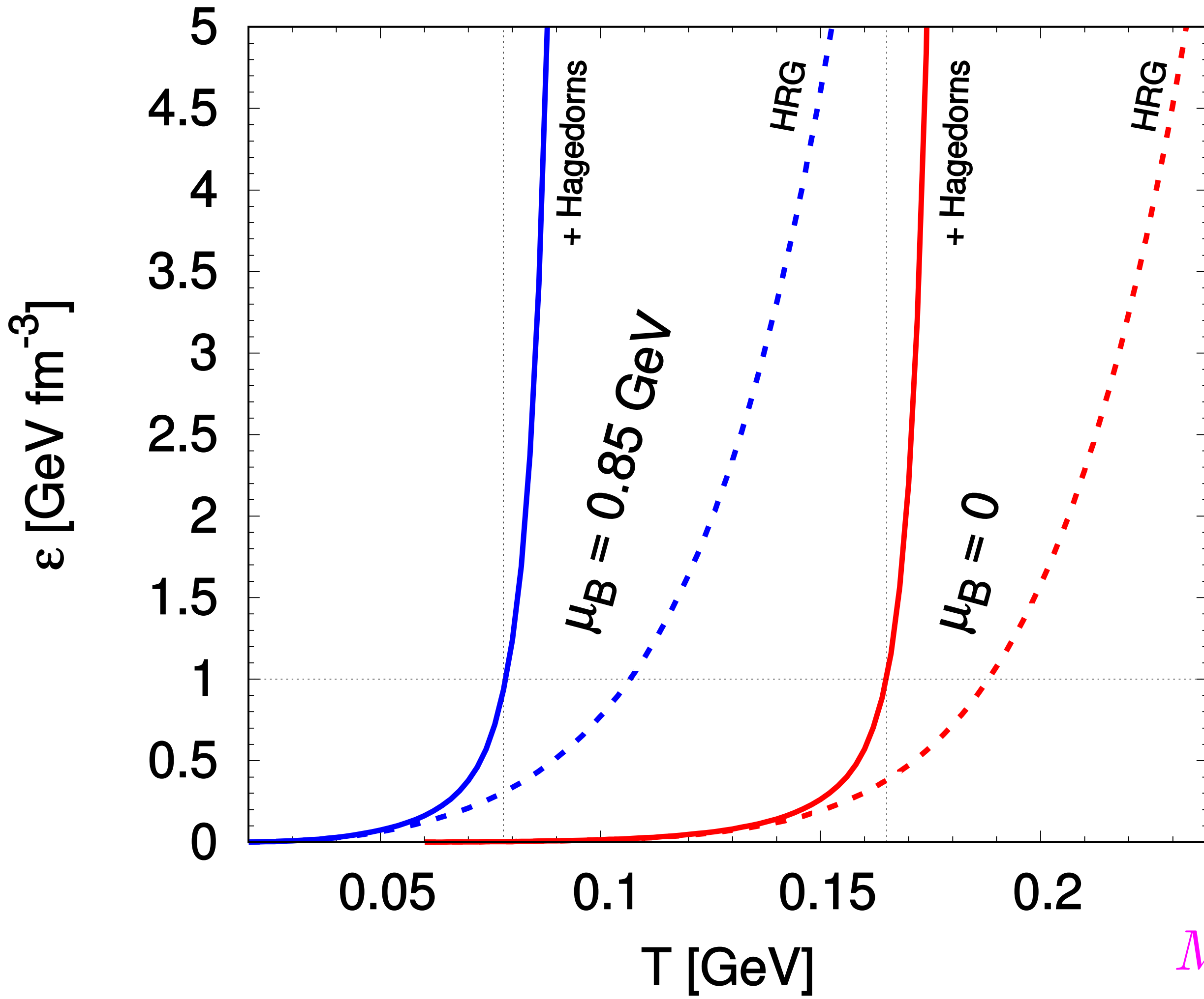
Radius ↗ : Width Γ ↘

T quite independent of charges

nonzero !

Energy Density

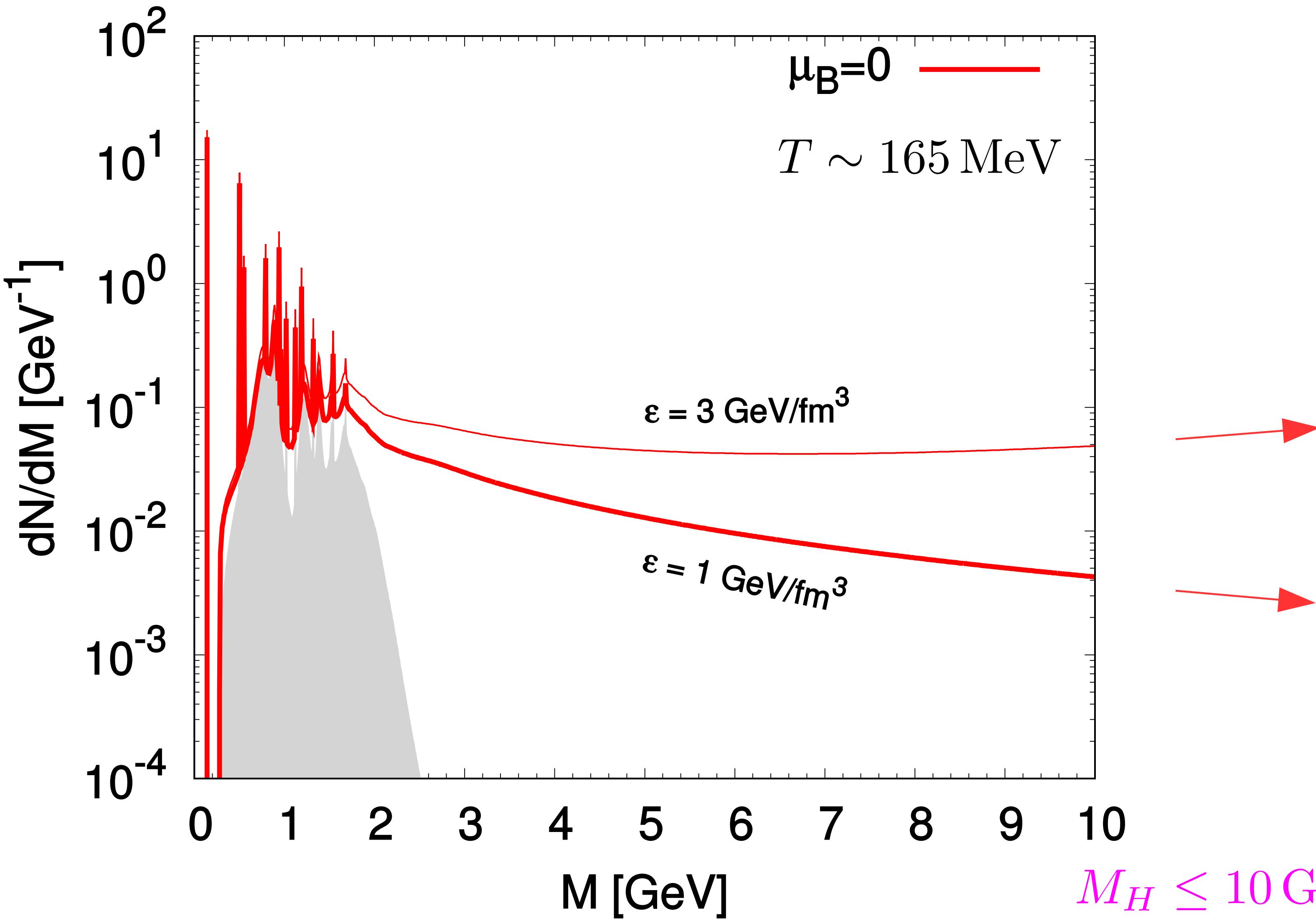
$$\varepsilon_H(T) \simeq \sum_{\vec{C}} \int \mathrm{d}m\, \tau_{\vec{C}}(m) \int p^2 \mathrm{d}p\, E\, \mathrm{e}^{-(E-\mu)/T}$$



$M_H \leq 10\,\mathrm{GeV}$

Divergence

exponential Hagedorn increase vs. thermal Boltzmann decrease



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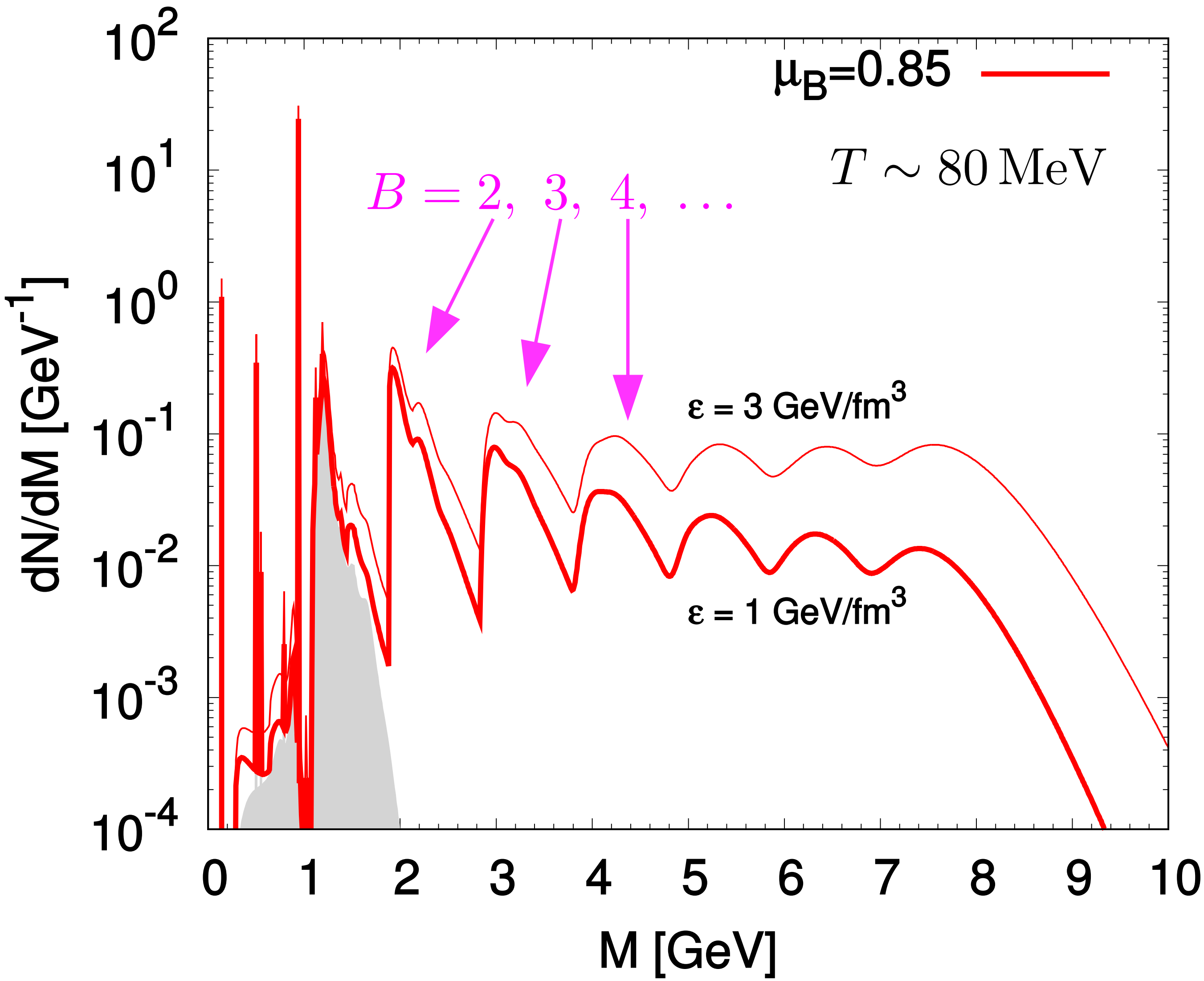
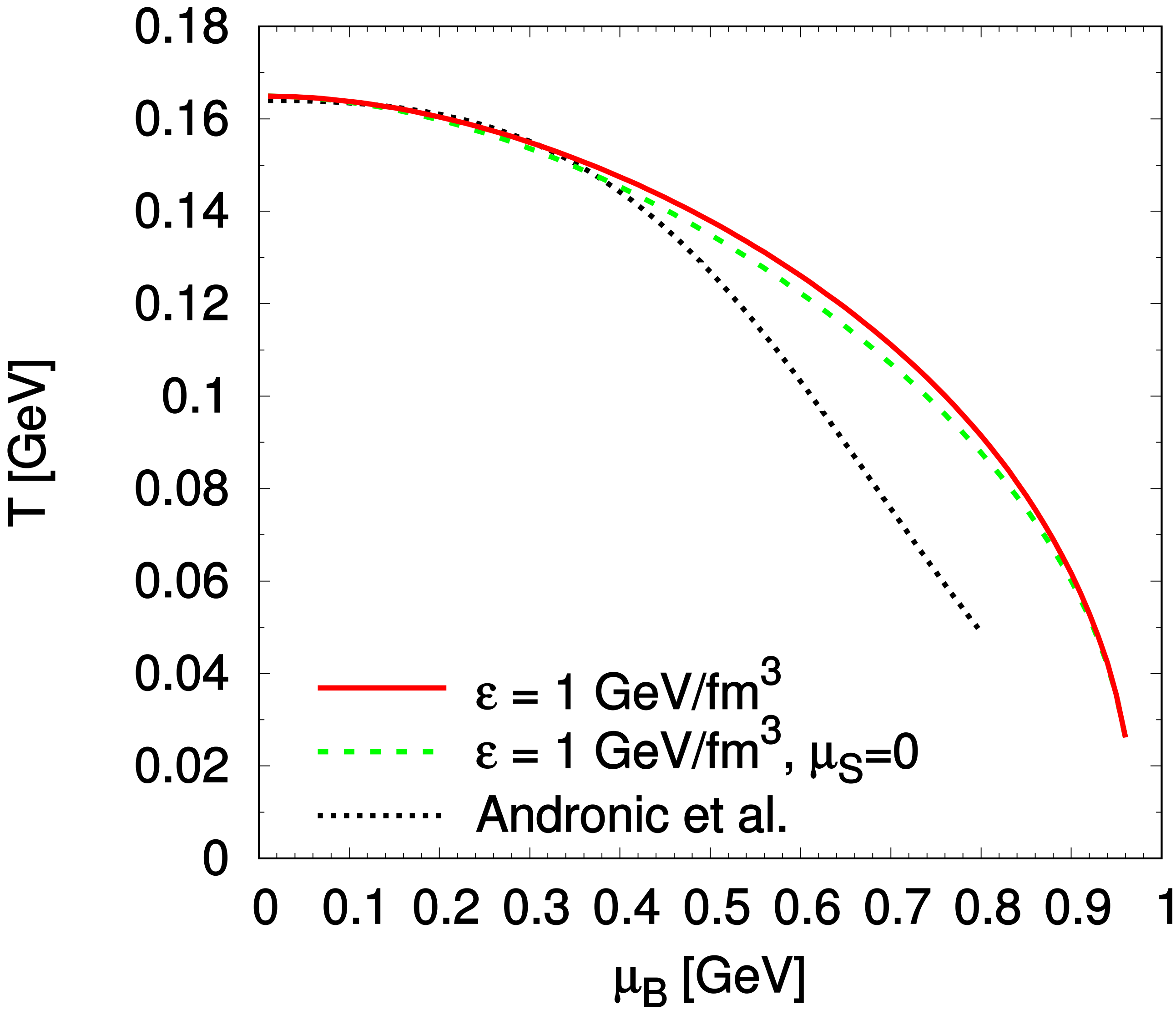
Divergence

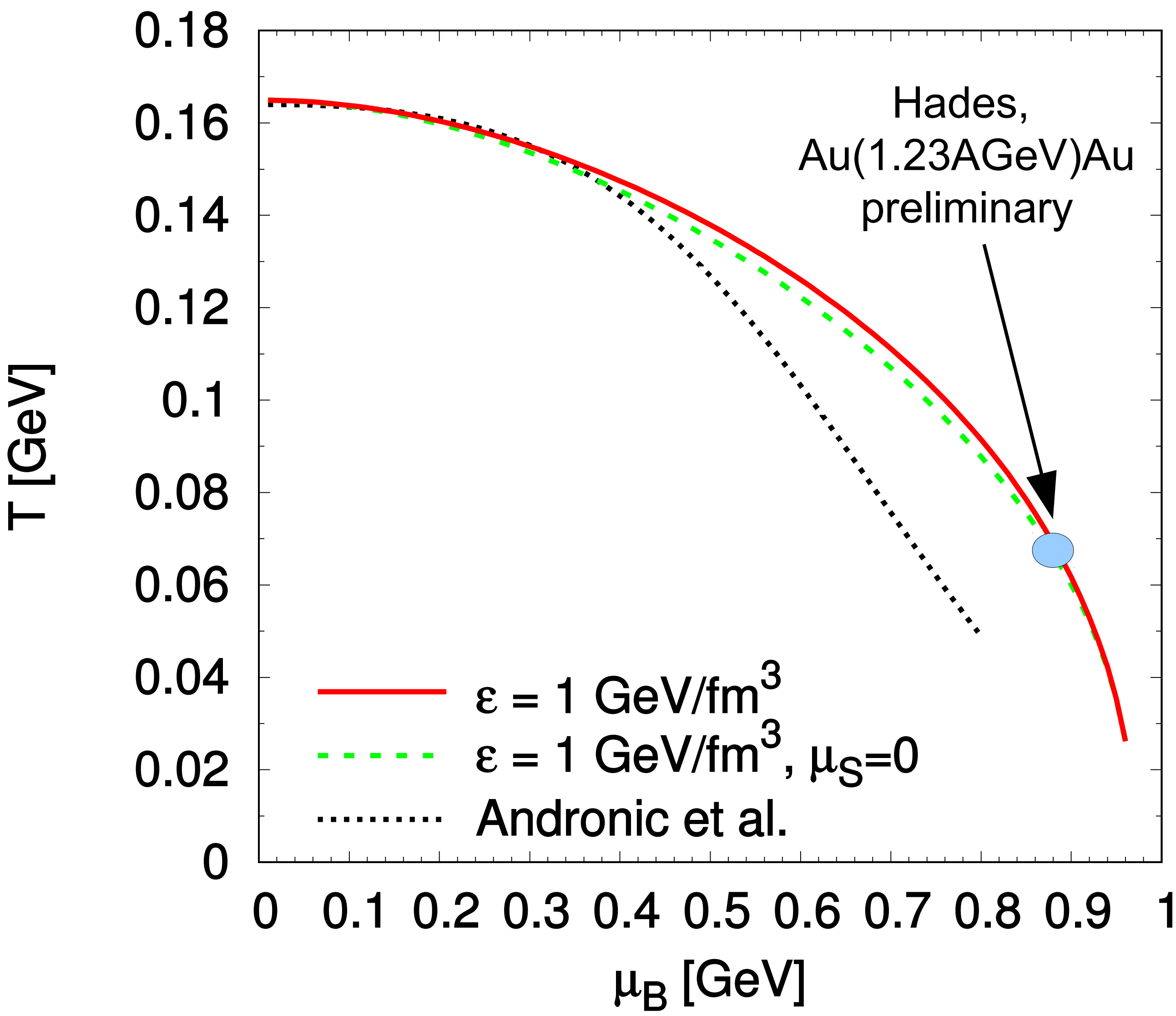


μ_B=0.85
$T \sim 80\,\mathrm{MeV}$
$B = 2,\ 3,\ 4,\ \ldots$
ε = 3 GeV/fm^3
ε = 1 GeV/fm^3
dN/dM [GeV^{-1}]
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 1 2 3 4 5 6 7 8 9 10
M [GeV]

‘Phase Boundary‘



‘Phase Boundary‘

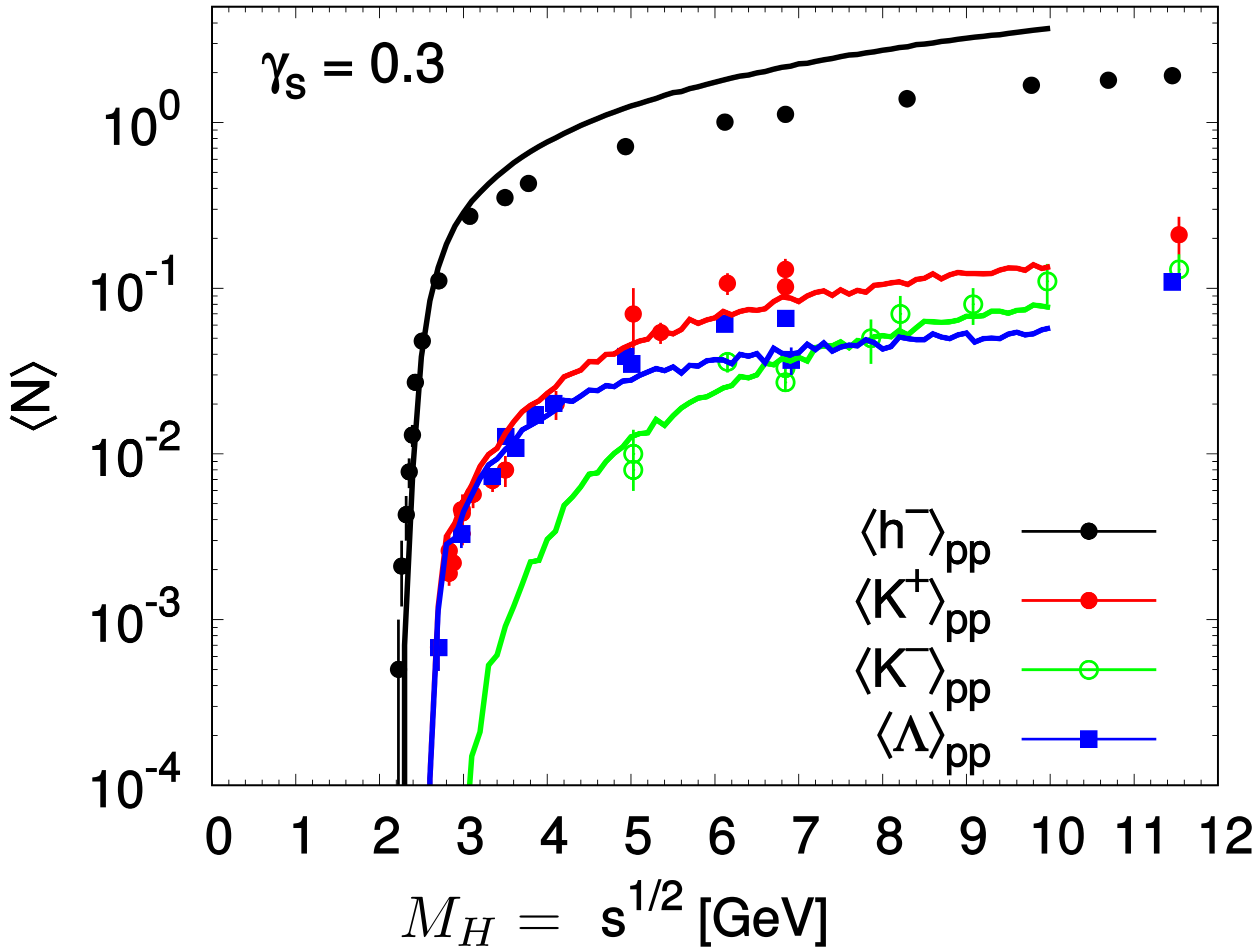


$T = 68 \pm 2\,\mathrm{MeV}$

$\mu_B = 883 \pm 25\,\mathrm{MeV}$

Strangeness Suppression

$pp \iff (B=2, S=0, I=1, I_z=1)$



$\gamma_s = 0.3$

$\gamma_\phi = \gamma_s^2$

$$\sigma \rightarrow \sigma\, \gamma_s^{(|S_1|+|S_2|-|S_1+S_2|)}$$

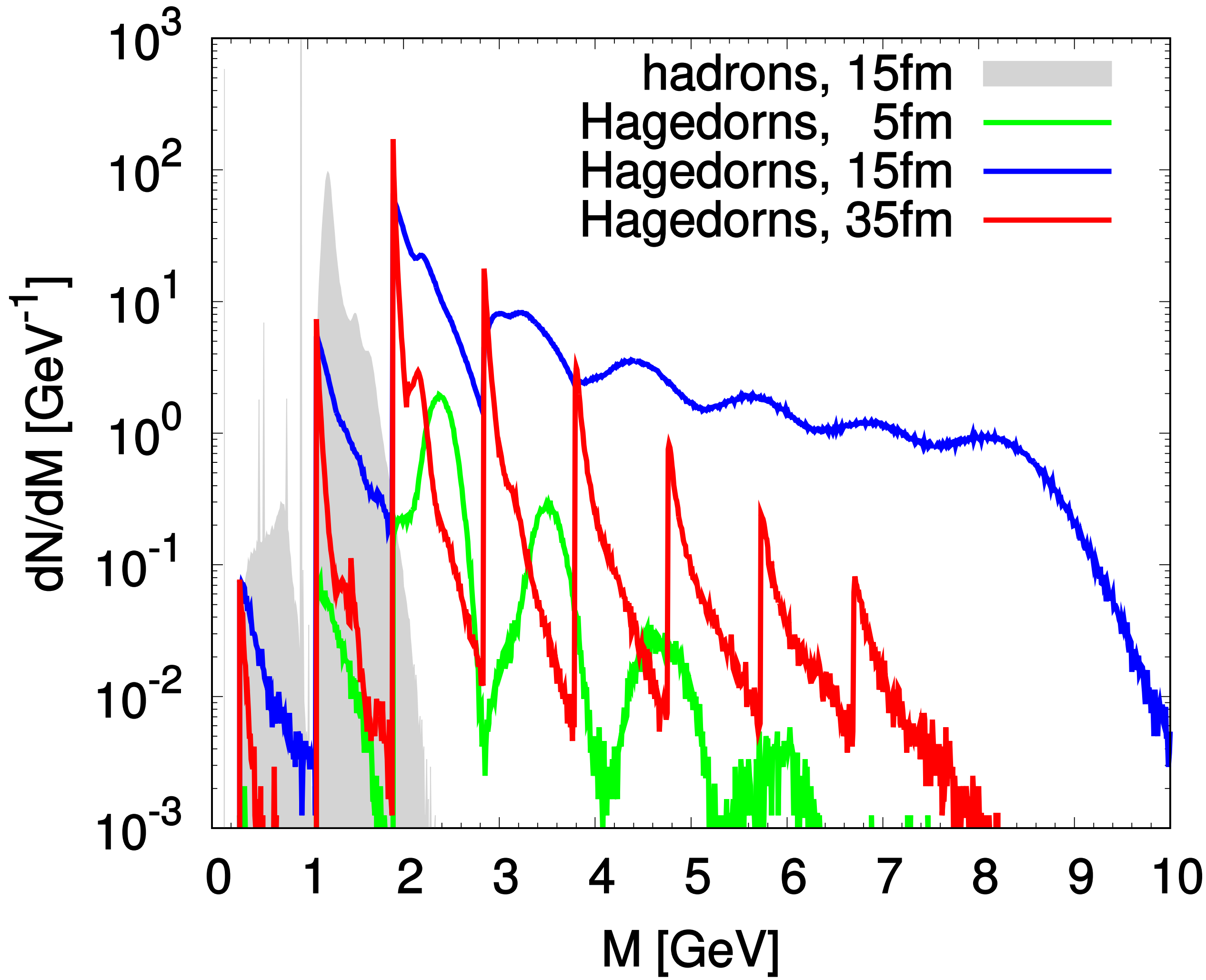
γ_s : penalty for $s\bar{s}$ pairs

γ_ϕ : penalty for ϕ meson

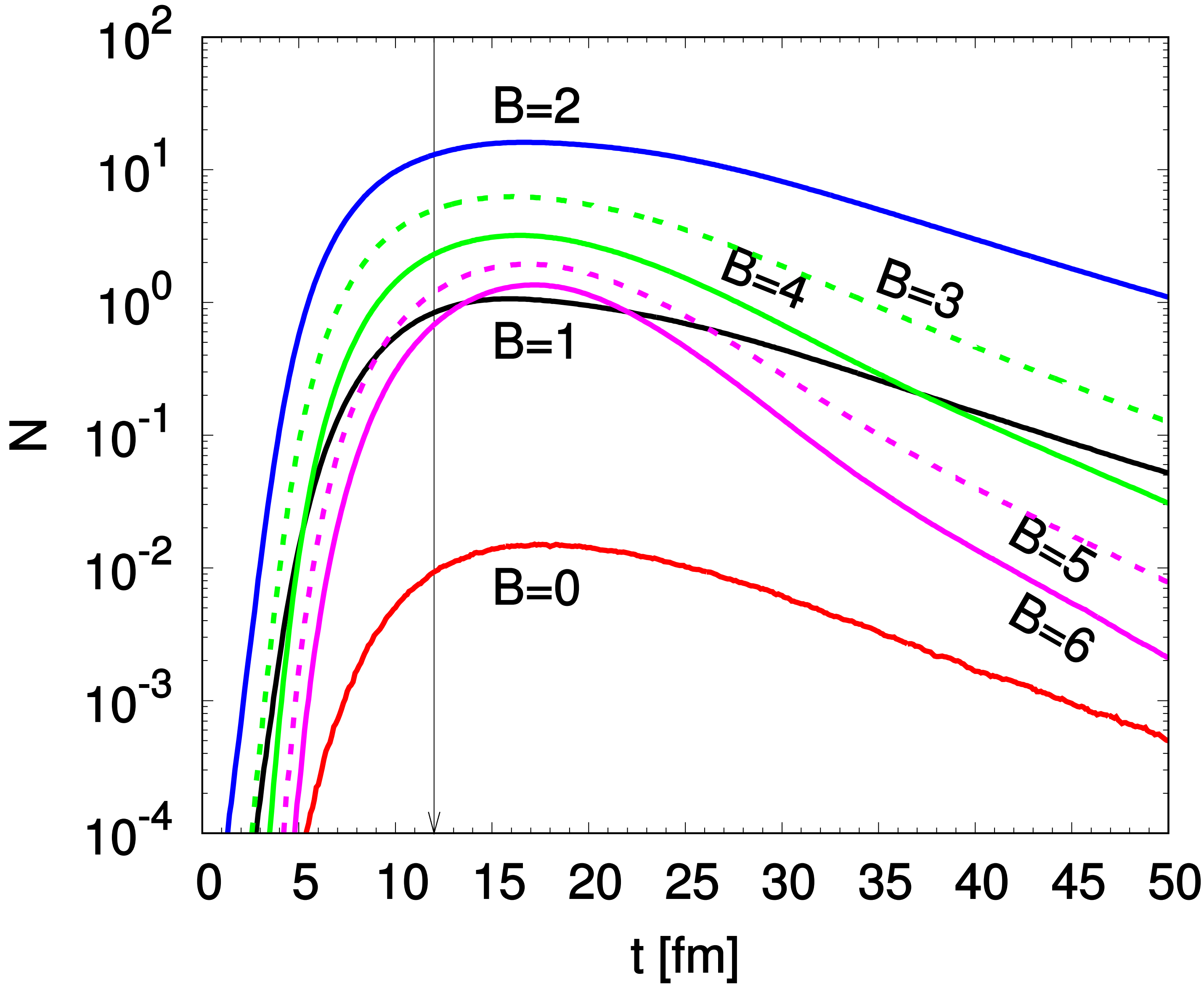
data compilation: Gazdzicki, Röhrich, Z.Phys.C65(1995)215, Z.Phys.C71(1996)55

Au(1.23 AGeV)Au, 0-40%

full dynamical calculation with Hagedorns in GiBUU

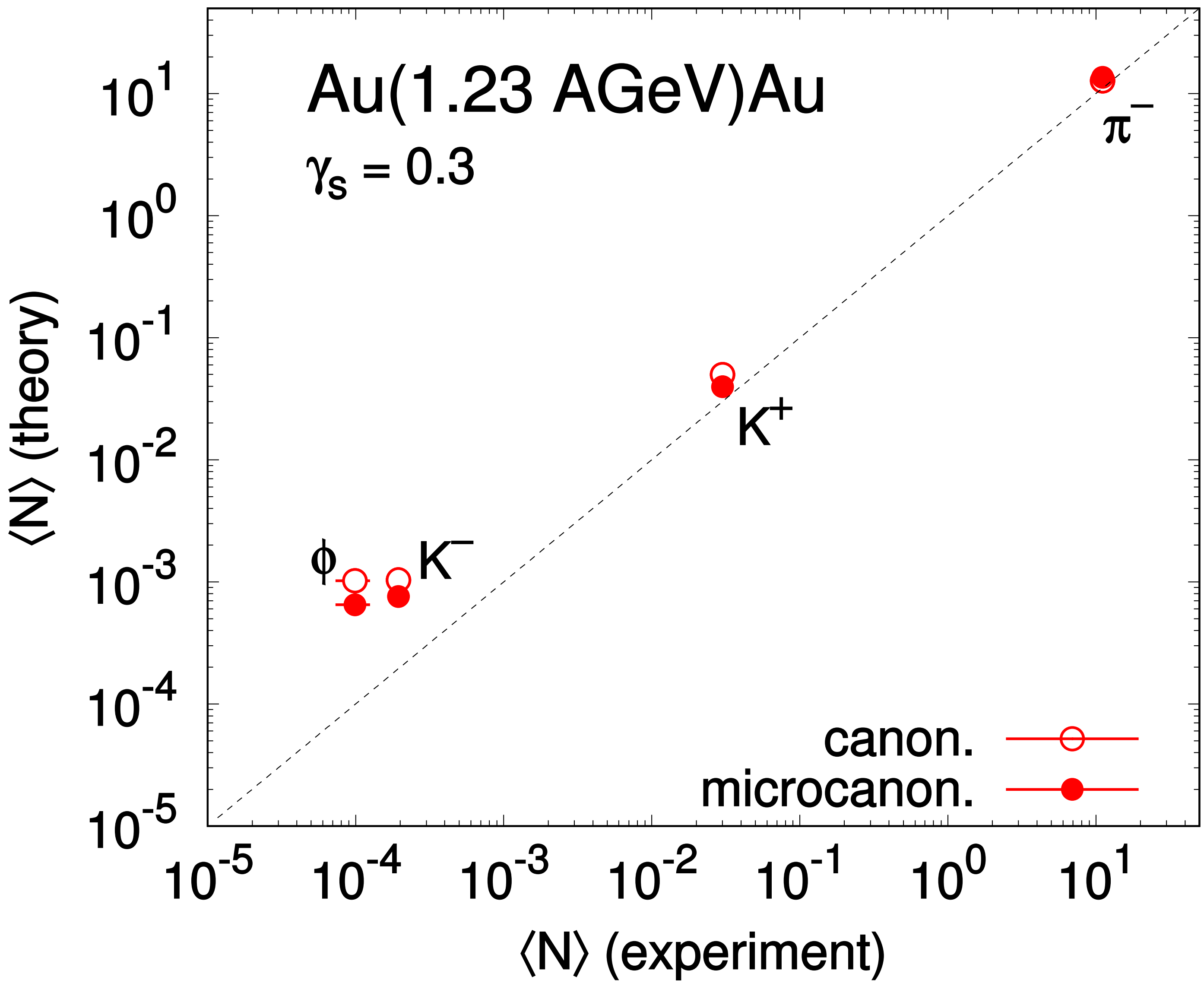


Au(1.23 AGeV)Au, 0-40%



Multiplicities

data: Adamczewski-Musch et al., arXiv:1703.08418



Multiplicities

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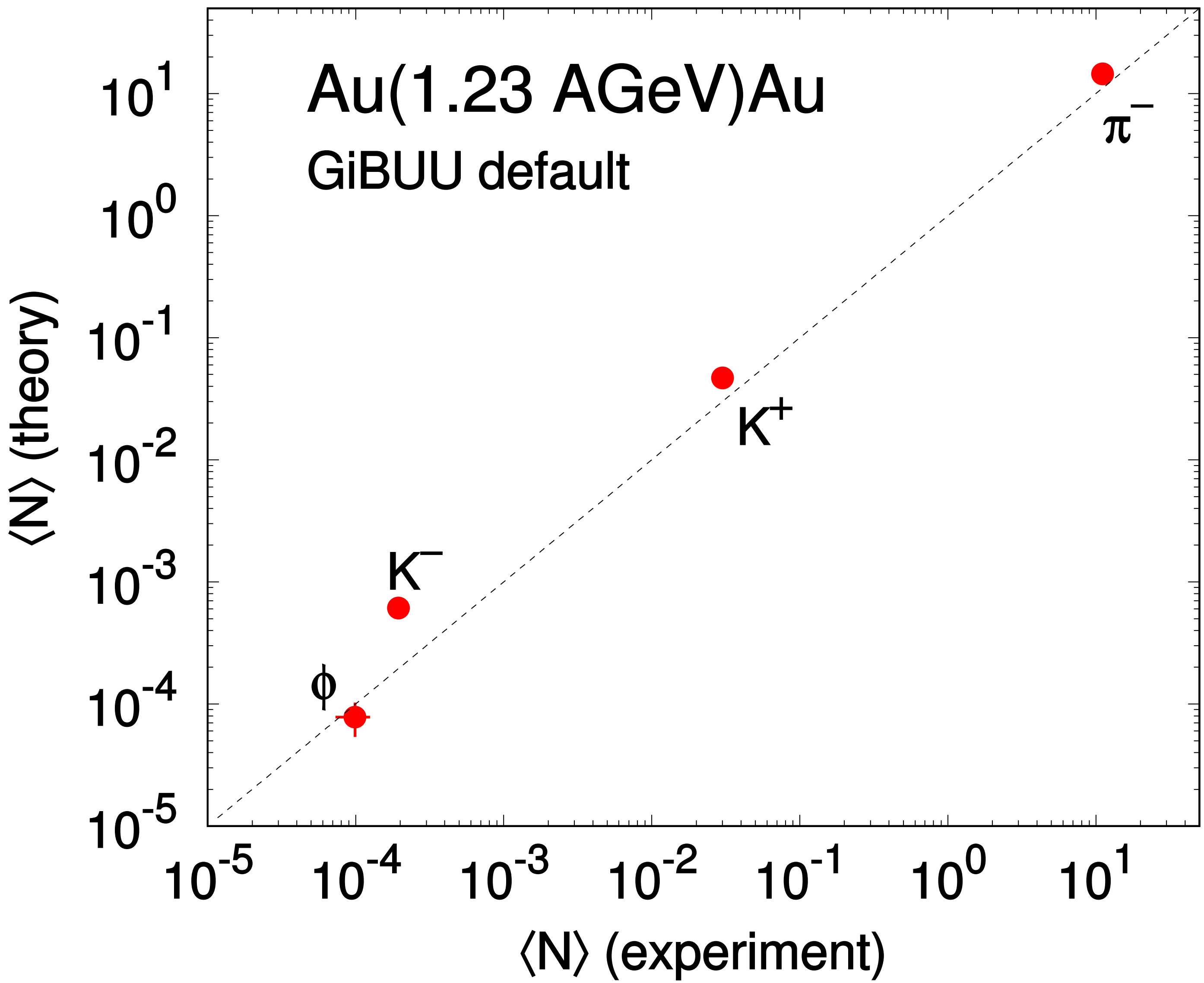
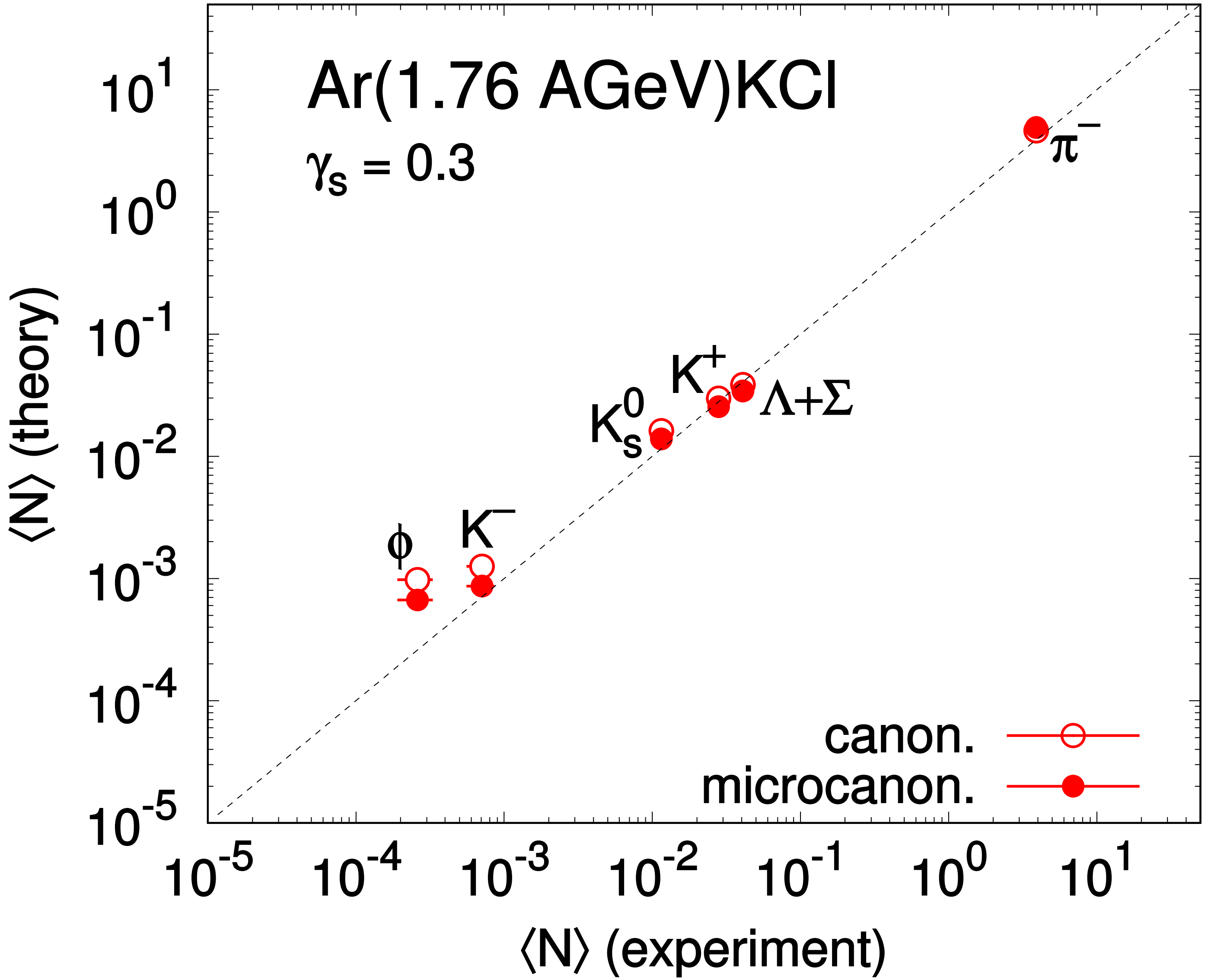


Multiplicities

data: Adamczewski-Musch et al., arXiv:1703.08418



Multiplicities

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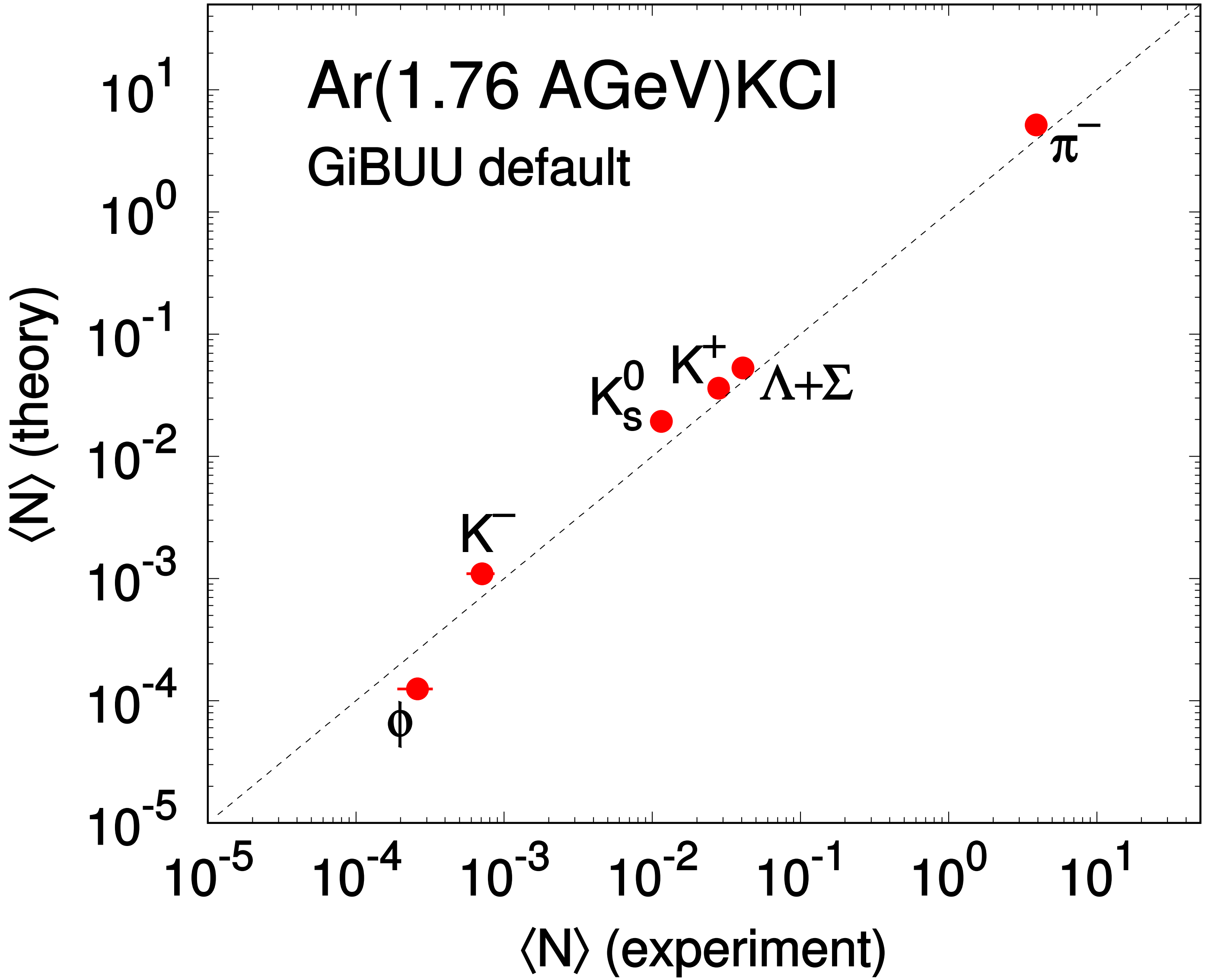


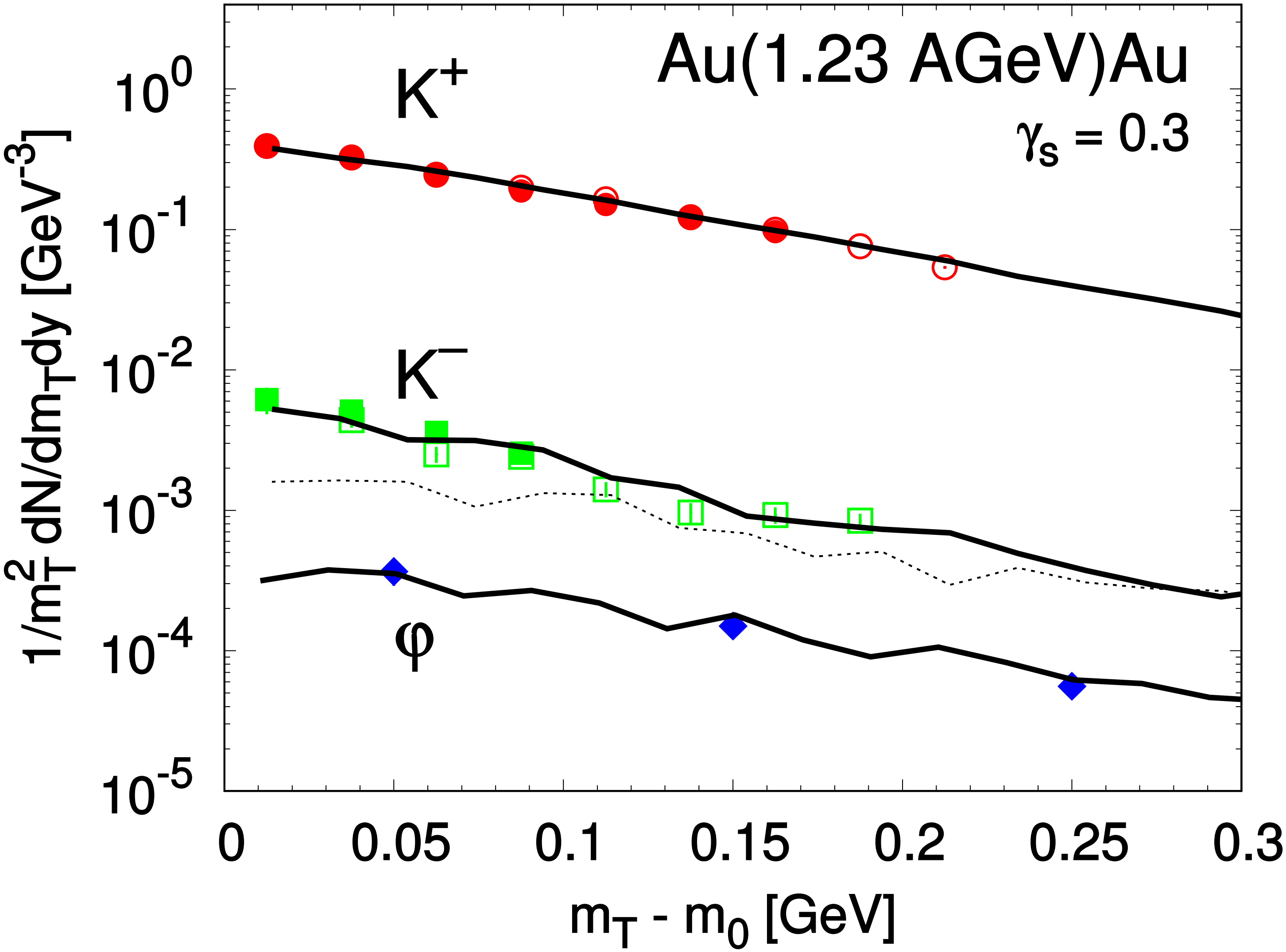
phi/K-

	Au(1.23)Au	Ar(1.76)KCl
HADES	0.52 ± 0.16	0.37 ± 0.13
Hagedorn	0.85 ± 0.11	0.77 ± 0.06
GiBUU	0.13 ± 0.04	0.11 ± 0.01

- phi-production:
  - Hagedorn: $H \to H\phi$
  - GiBUU: $\pi\rho \to \phi \quad , \quad N\pi \to N\phi$
- Hagedorn picture not fine-tuned:
  - NN features: γ_s, γ_φ
  - σ=30 mb (hadronic phi-absorption cross section larger!)
  - ...

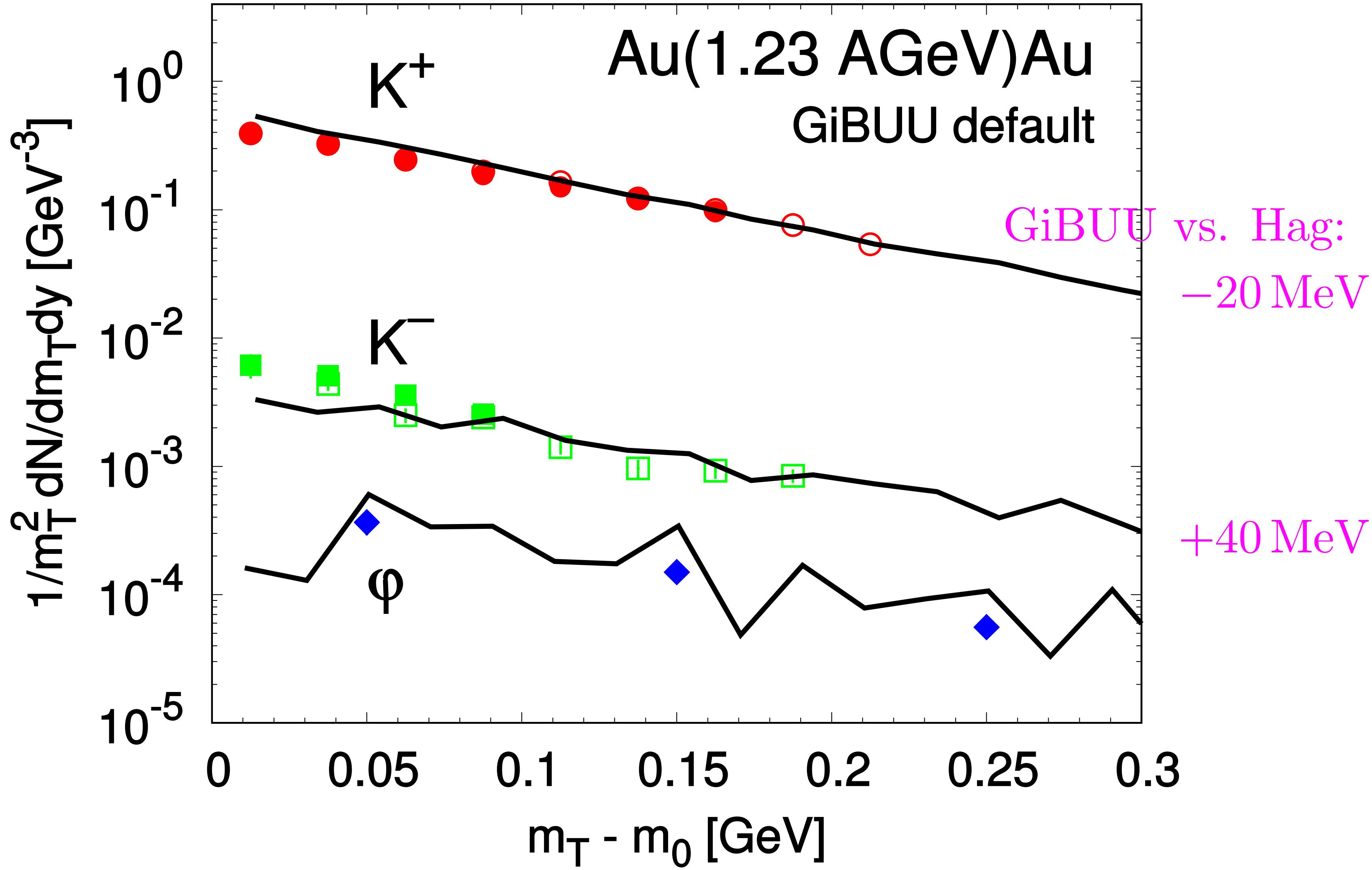
Slopes

data: Adamczewski-Musch et al., arXiv:1703.08418



Slopes

data: Adamczewski-Musch et al., arXiv:1703.08418



Conclusions

- for the first time Hagedorn states incorporated into full dynamical transport calculations

- Heavy Ion Collisions at SIS18 energies
- different/alternative strangeness production scenario
- not fine-tuned

- phi/K- enhanced
- slopes better (?) described

- charm production?
- light nuclei? (deuteron, triton, ...)