Hagedorn States and (anti-)(hyper-)nuclei production in HIC

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Hagedorn bootstrap

light nuclei

full dynamical calculations

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

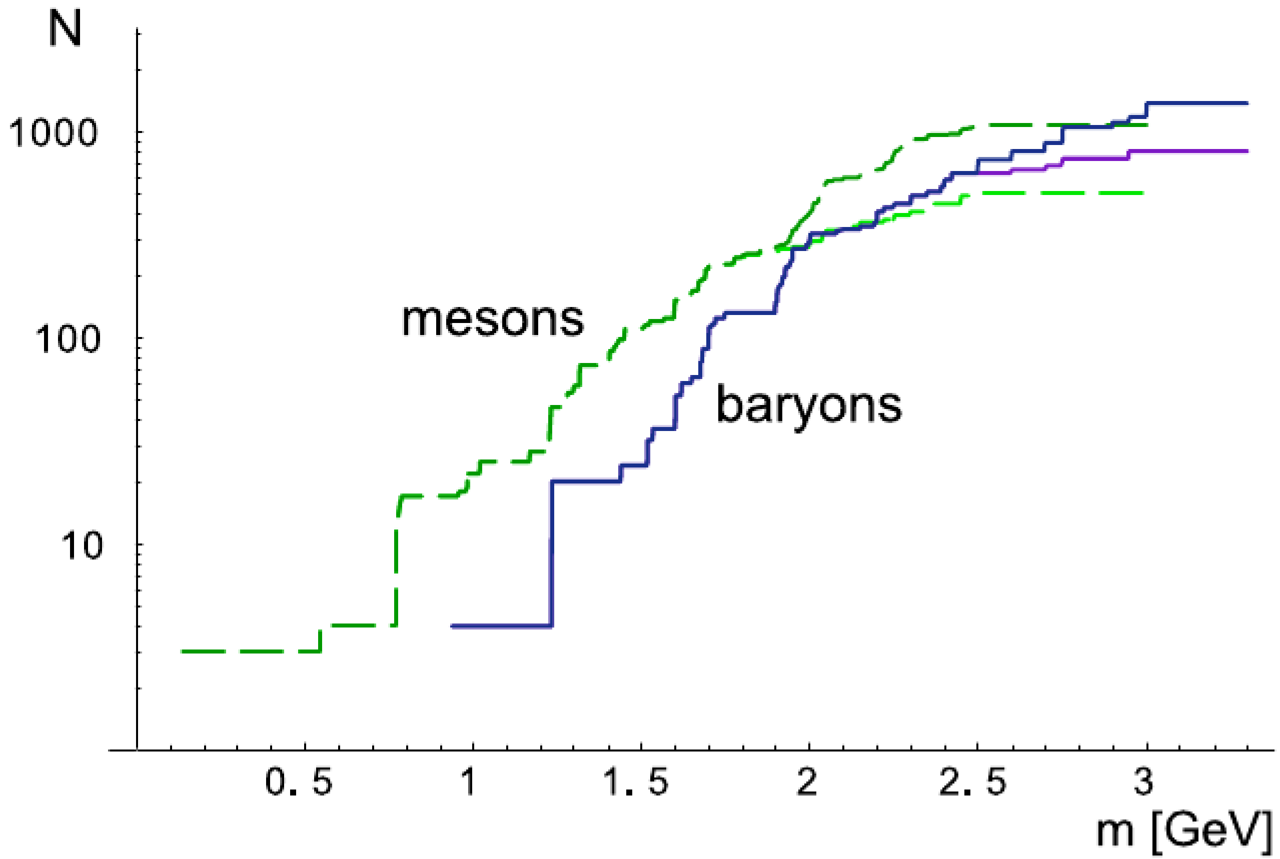
Bundesministerium für Bildung und Forschung

3rd EMMI workshop:
Anti-matter, hyper-matter and exotica @ LHC
Wroclaw, 2-6 Dec 2019

hadronic states

- accumulated spectrum of PDG states

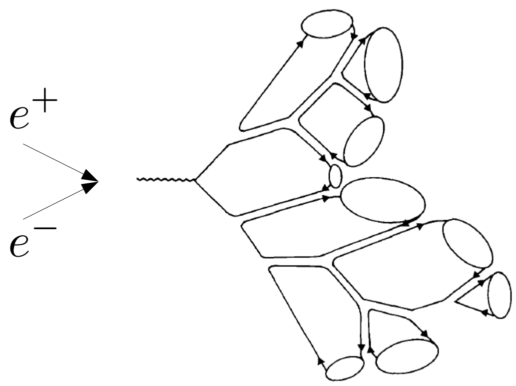
W.Broniowski, W.Florkowski, L.Glozman, PRD 70 (2004) 117503



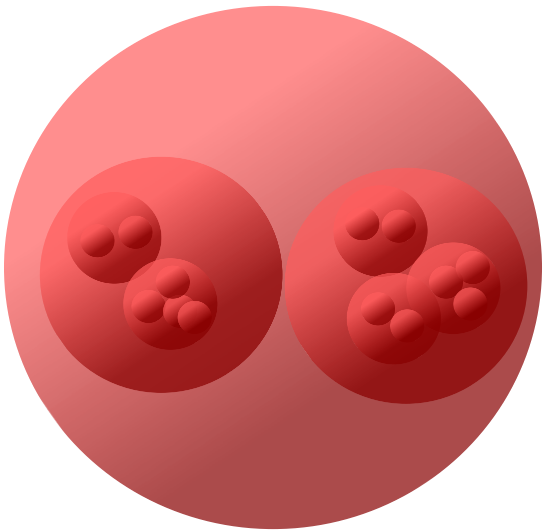
higher masses???

colorless heavy objects

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

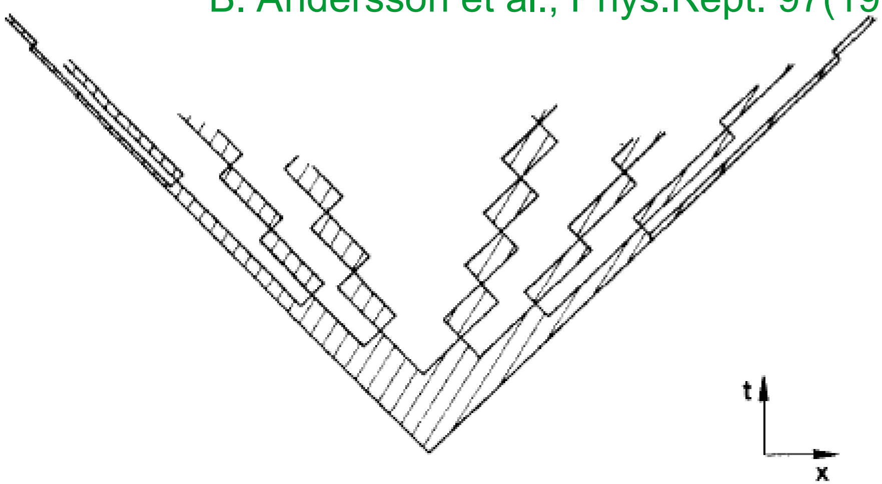


- Hagedorn states
  R. Hagedorn, Nuovo Cim. Suppl. 3 (1965) 147



allow for
decay & recombination !!!

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



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

$$\vec{C} = \text{quantum numbers}$$
$$\vec{C} = (B, S, Q)$$
$$\vec{C} = (B, S, I)$$

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

non-linear integral equation, Volterra type

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

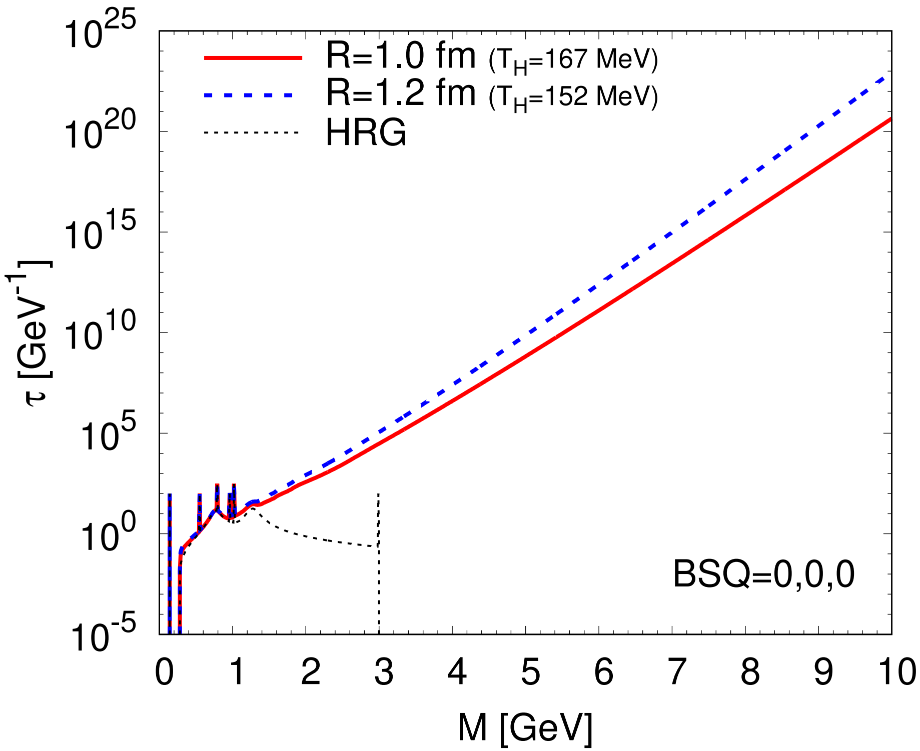
$$V(m) = V = \frac{4}{3}\pi R^3 \qquad\qquad R \sim 1\,\mathrm{fm}$$

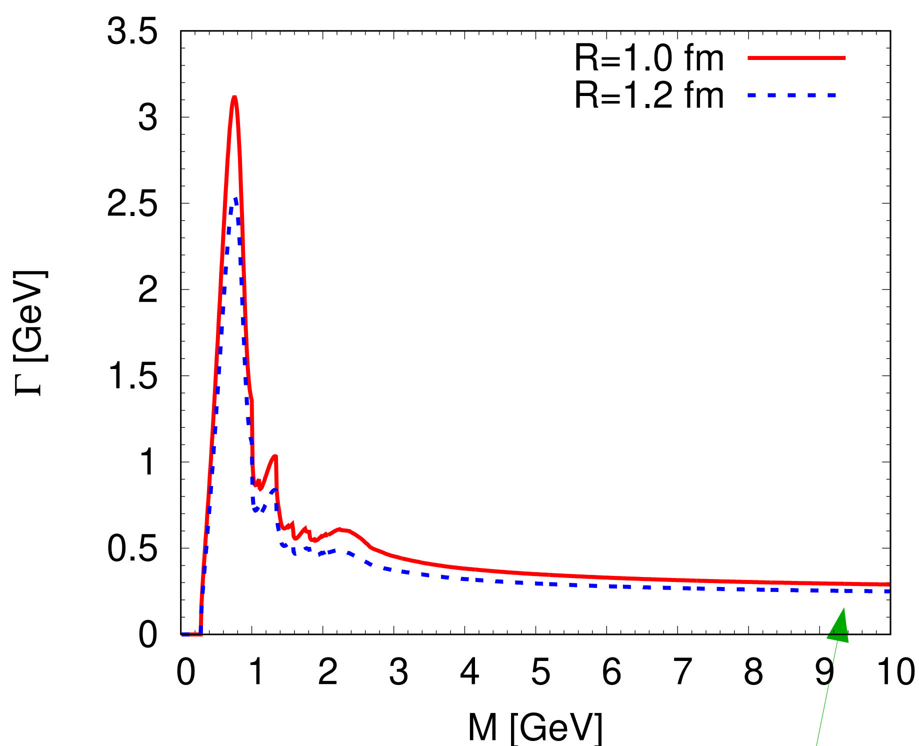
$$\sigma \sim 30\,\mathrm{mb}$$

$$\sigma(m) = \sigma = \pi R^2 \qquad\qquad T_H \sim 160\,\mathrm{MeV}$$

spectra, width

$$\tau(m) \sim m^{-b}\, \mathrm{e}^{m/T_H}$$





radius ↗ : slope T_H ↘

radius ↗ : width Γ ↘

T_H quite independent of charges

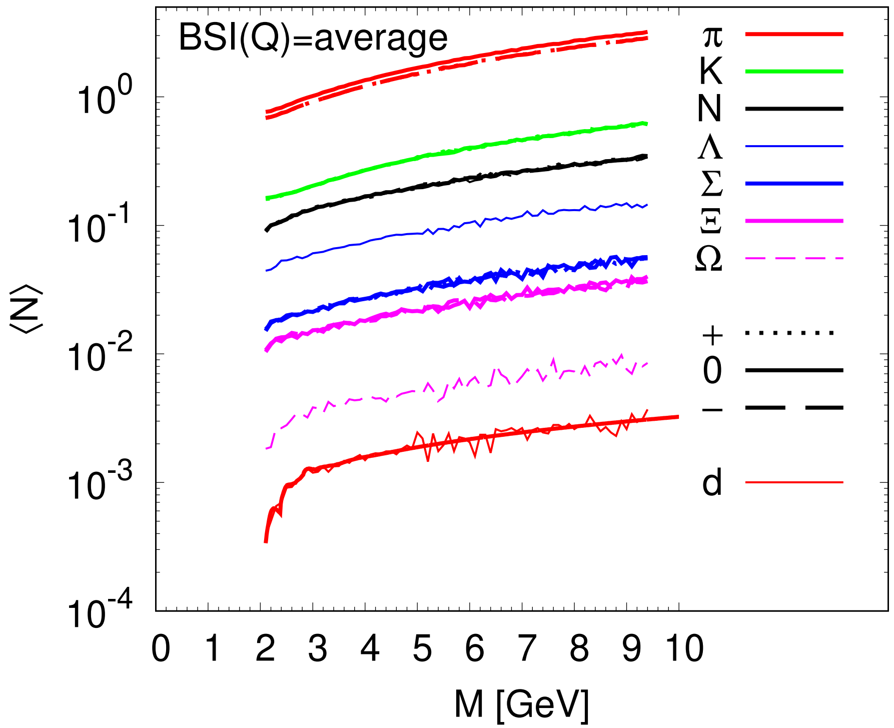
nonzero !

light nuclei

- include $^{2}\mathrm{H},\ ^{3}\mathrm{H},\ ^{3}\mathrm{He},\ ^{3}_{\Lambda}\mathrm{H},\ ^{4}\mathrm{He}$

  eg: $\tau^{0}_{(200)}(m) \mathrel{+}= g_s\,\delta(m - m_d)$

- problem: multiplicity in MC decay

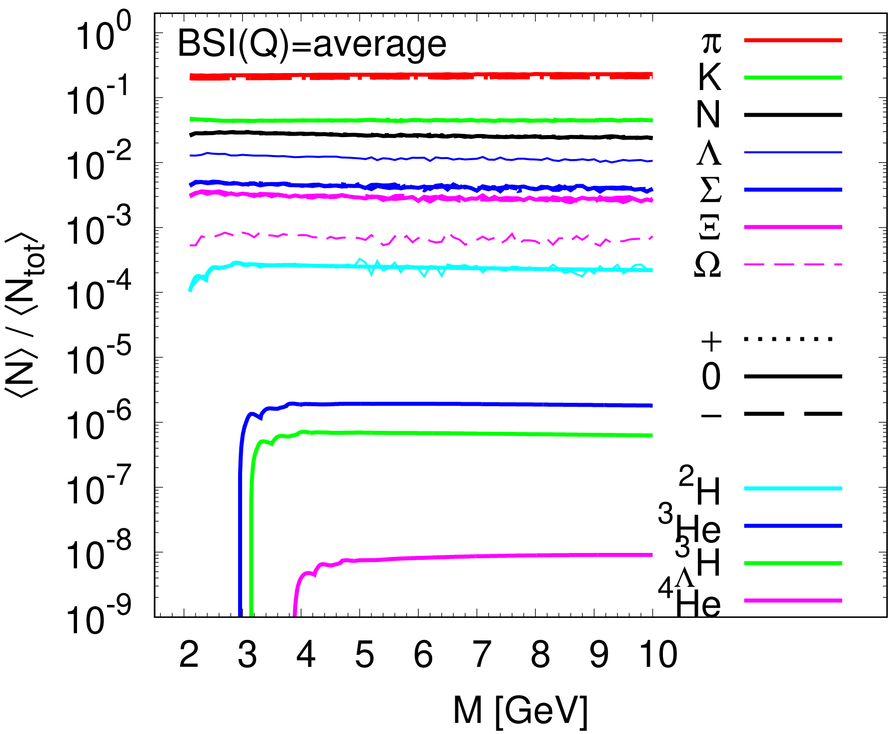


light nuclei

- pre-calculate decay multiplicities (cf. bootstrap)

$$n_{\vec{C}}^{(\mathrm{A})}(m) = \sum_{\vec{C}_1,\vec{C}_2}^{*} \iint \mathrm{d}B_{\vec{C};\vec{C}_1,\vec{C}_2}(m,m_1,m_2)\,\left(n_{\vec{C}_1}^{(\mathrm{A})}(m_1) + n_{\vec{C}_2}^{(\mathrm{A})}(m_2)\right)$$

$$\mathrm{d}B_{\vec{C};\vec{C}_1,\vec{C}_2}(m,m_1,m_2) = \frac{1}{(2\pi)^2}\,\frac{\sigma(m)}{\Gamma_{\vec{C}}(m)}\,\frac{\tau_{\vec{C}_1}(m_1)\tau_{\vec{C}_2}(m_2)}{\tau_{\vec{C}}(m)-\tau_{\vec{C}}^{0}(m)}\,p_{\mathrm{cm}}^2(m,m_1,m_2)\,\mathrm{d}m_1\mathrm{d}m_2$$

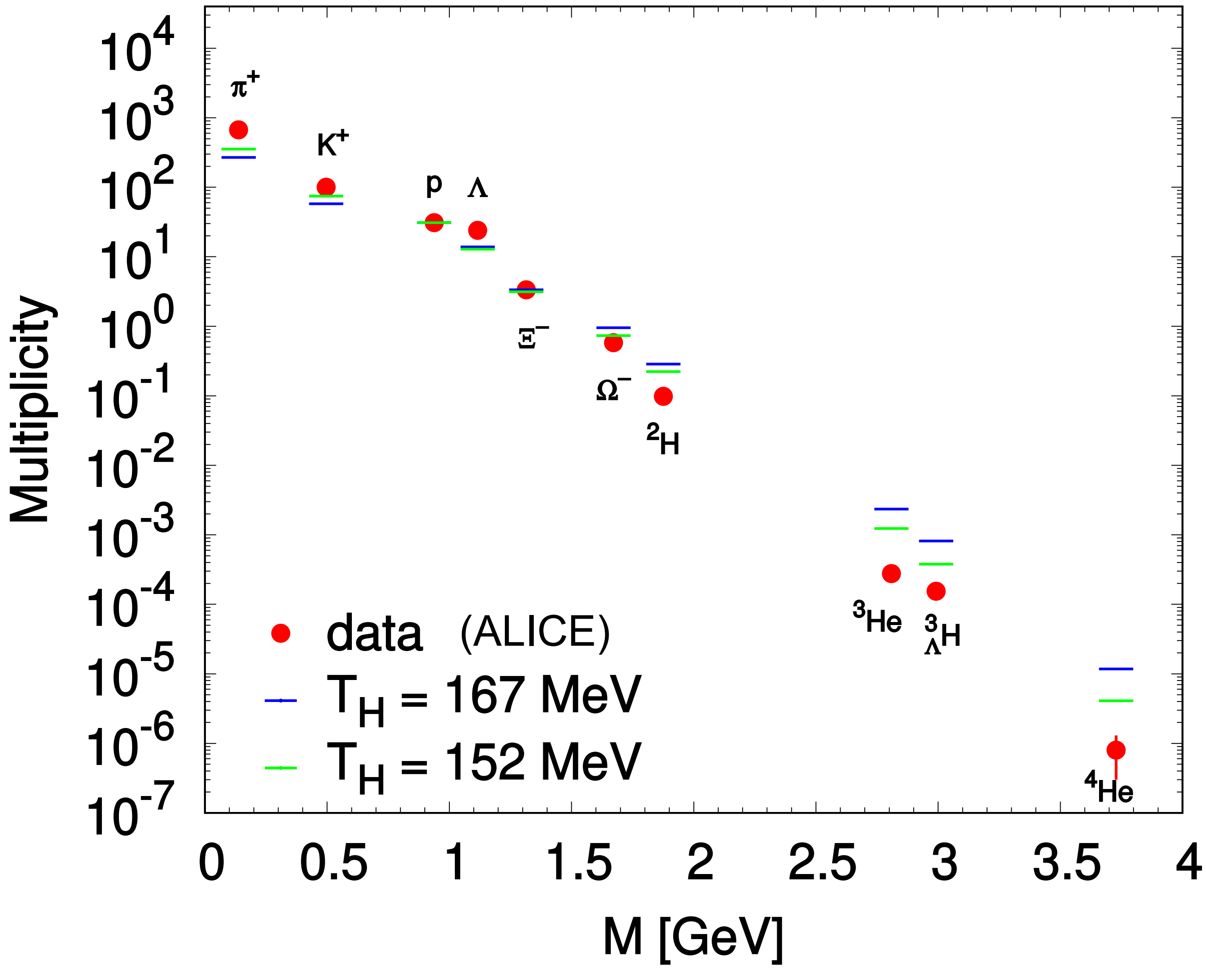


$$\langle N_{\mathrm{tot}}\rangle \simeq 0.27 + 1.44\,\mathrm{GeV}^{-1}\,M$$

relative multiplicities nearly independent of M

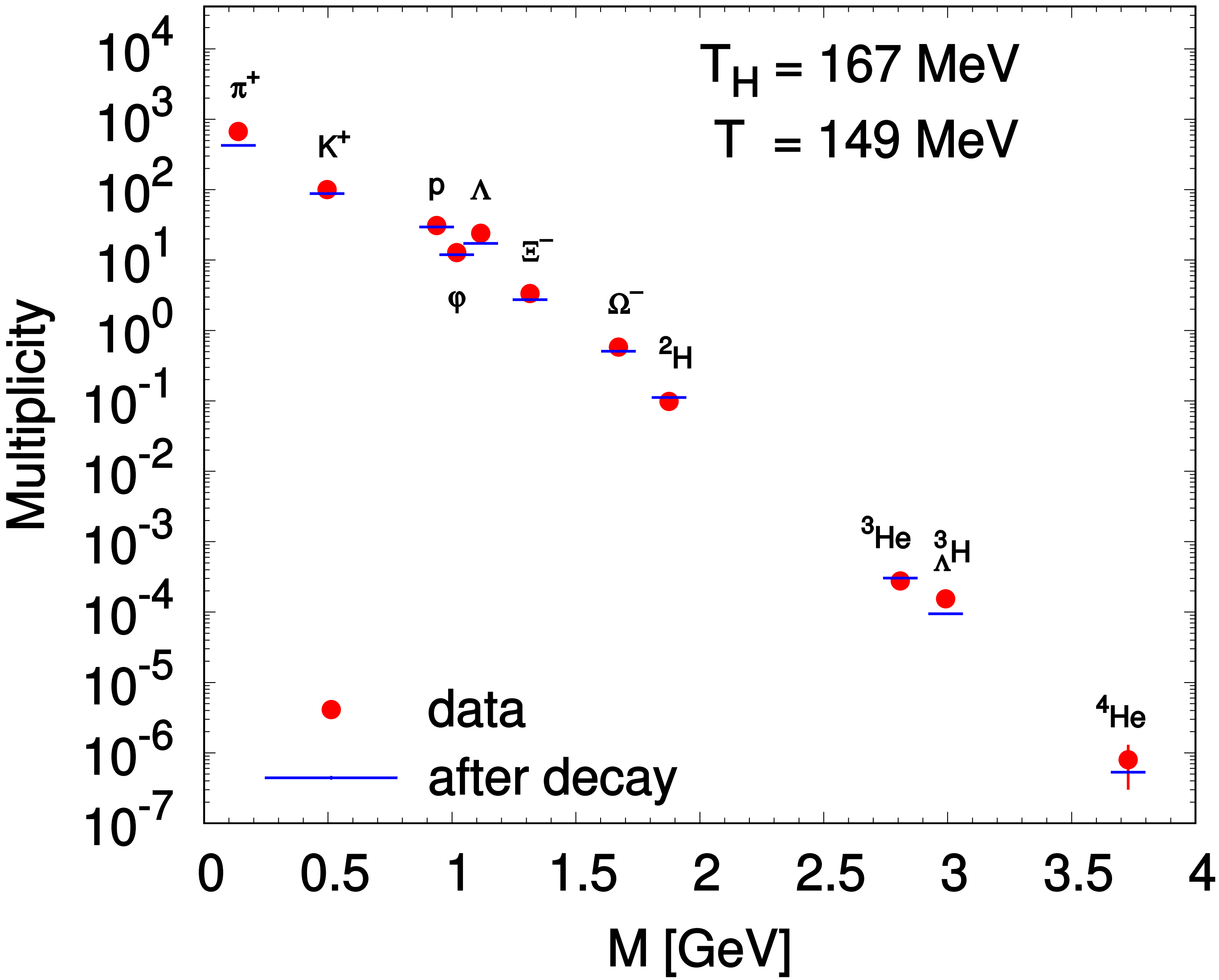
single Hagedorn decay chain

- *B*,*S*,*I*: averaged according $\tau_{(BSI)}(M)$
- M=10 GeV (M≳4GeV: branchings nearly independent of M)



(normalized to p)

thermal Hagedorn gas



equivalent:
T_H = 152 MeV
T = 144 MeV

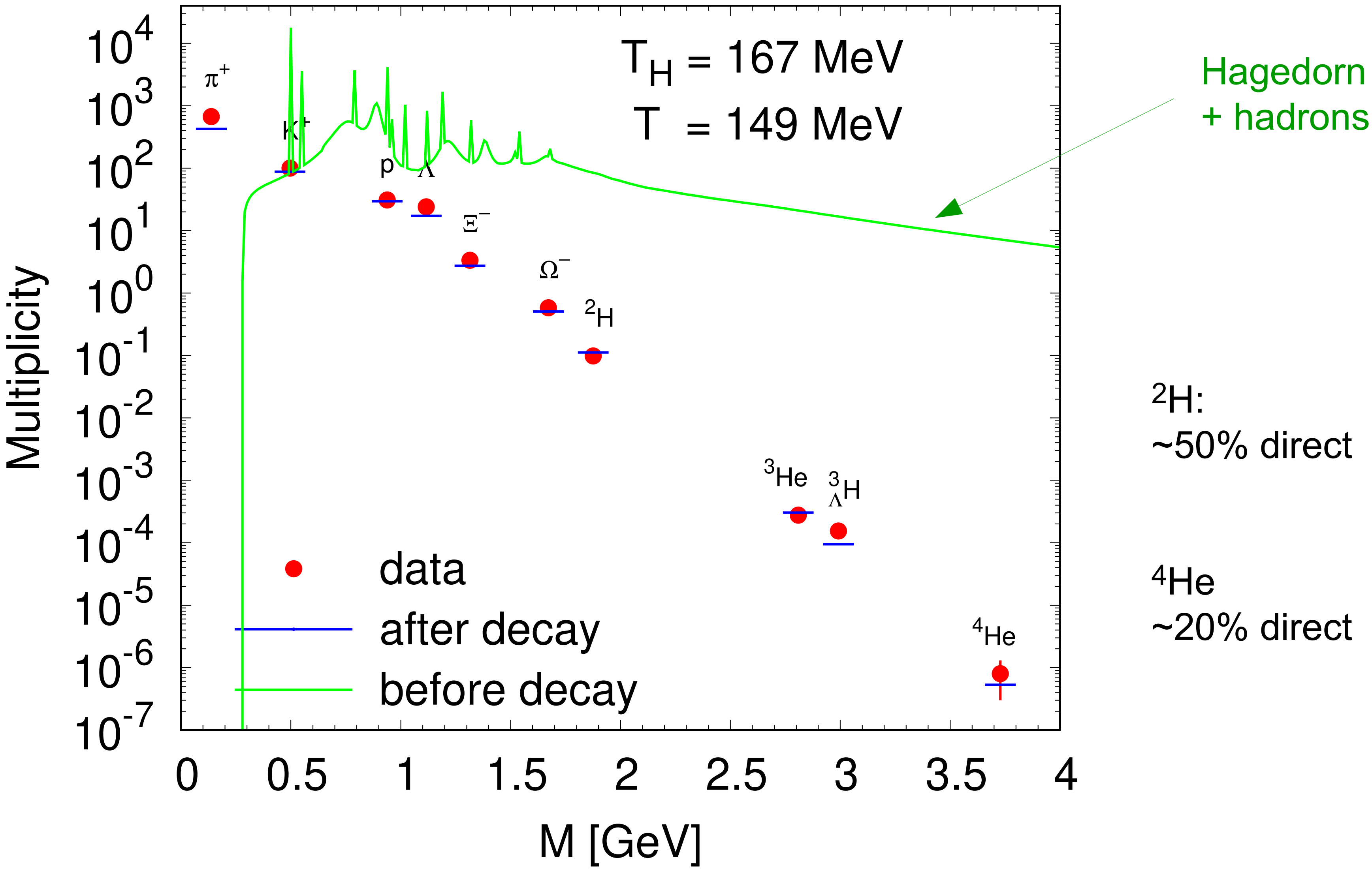
(fit to p&light nuclei)

^{2}H:
~50% direct

^{4}He
~20% direct

⇓
not just a Boltzmann factor !

thermal Hagedorn gas

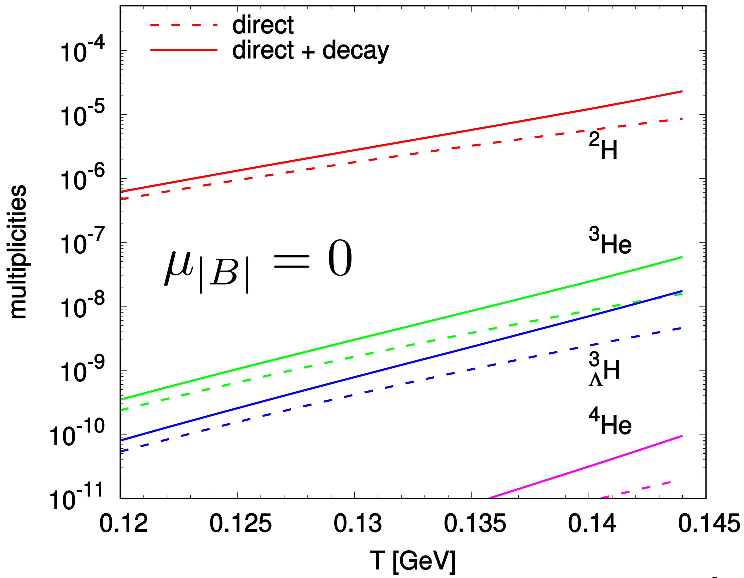


^{2}H:
~50% direct

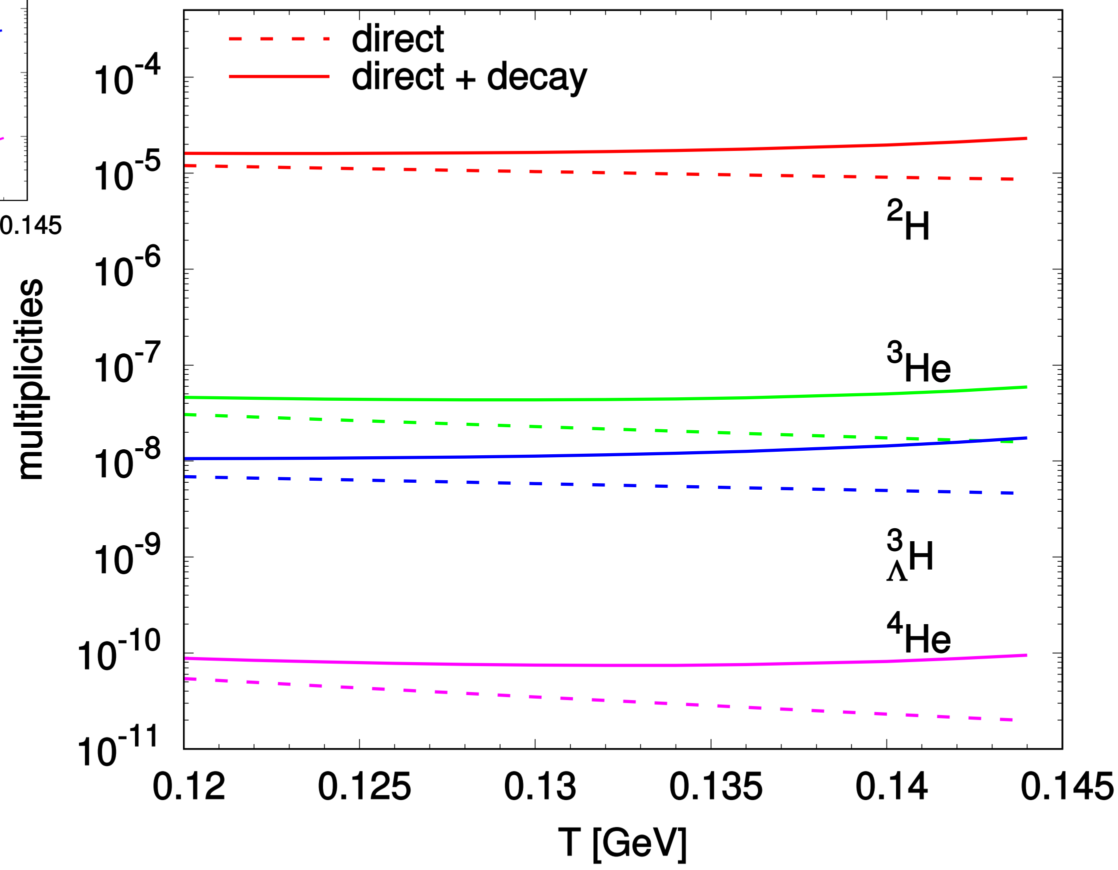
^{4}He
~20% direct

Hagedorn and Saha equation

cf.: V.Vovchenko et al., arXiv:1903.10024



$$\mu_{|B|} = \mu_{|B|}(T)$$ (fixed before decay)

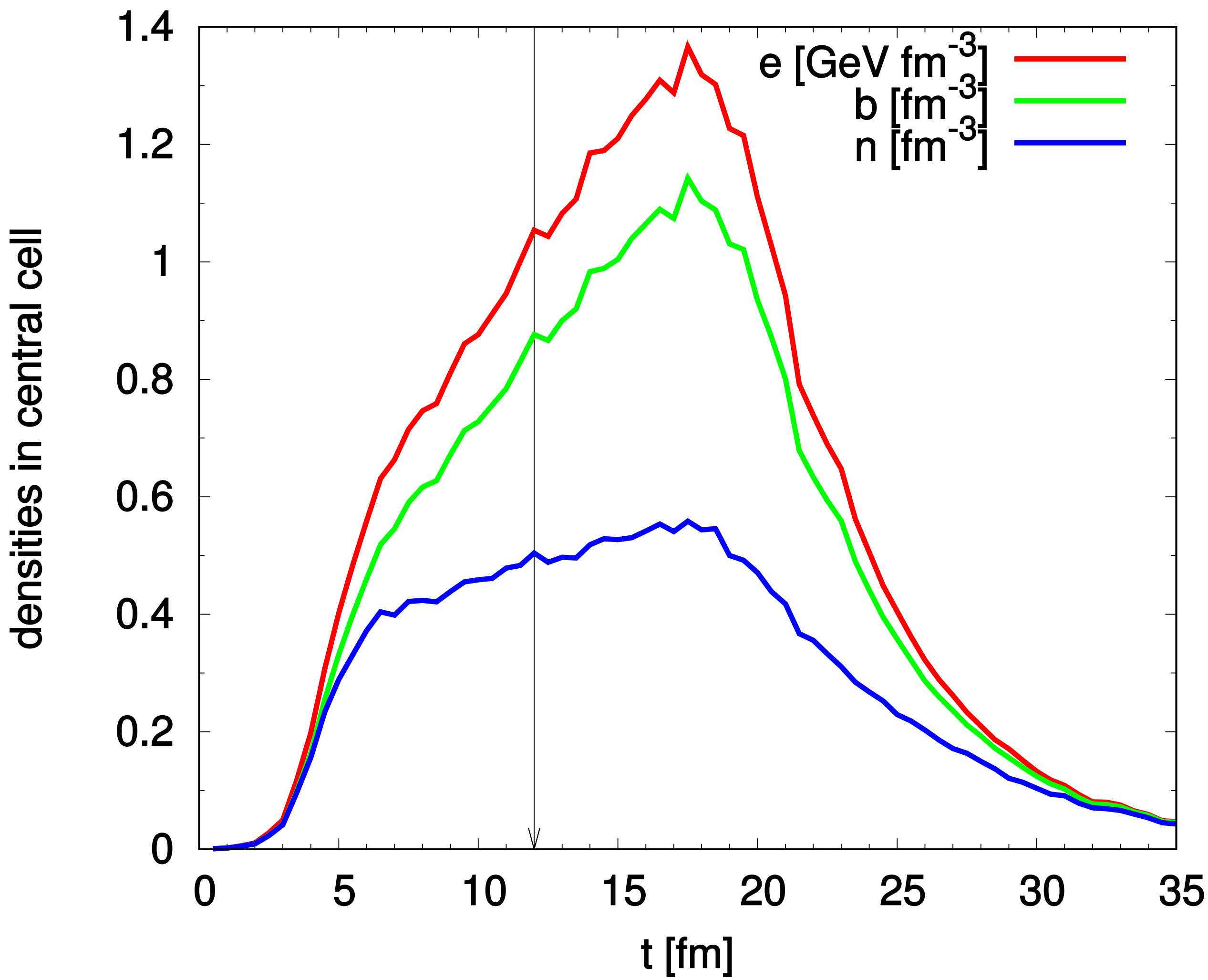


yields do not depend on temperature

Au(1.23 AGeV)Au, 0-40%

K.Gallmeister, M.Beitel, C.Greiner, PRC 98 (2018) 024915

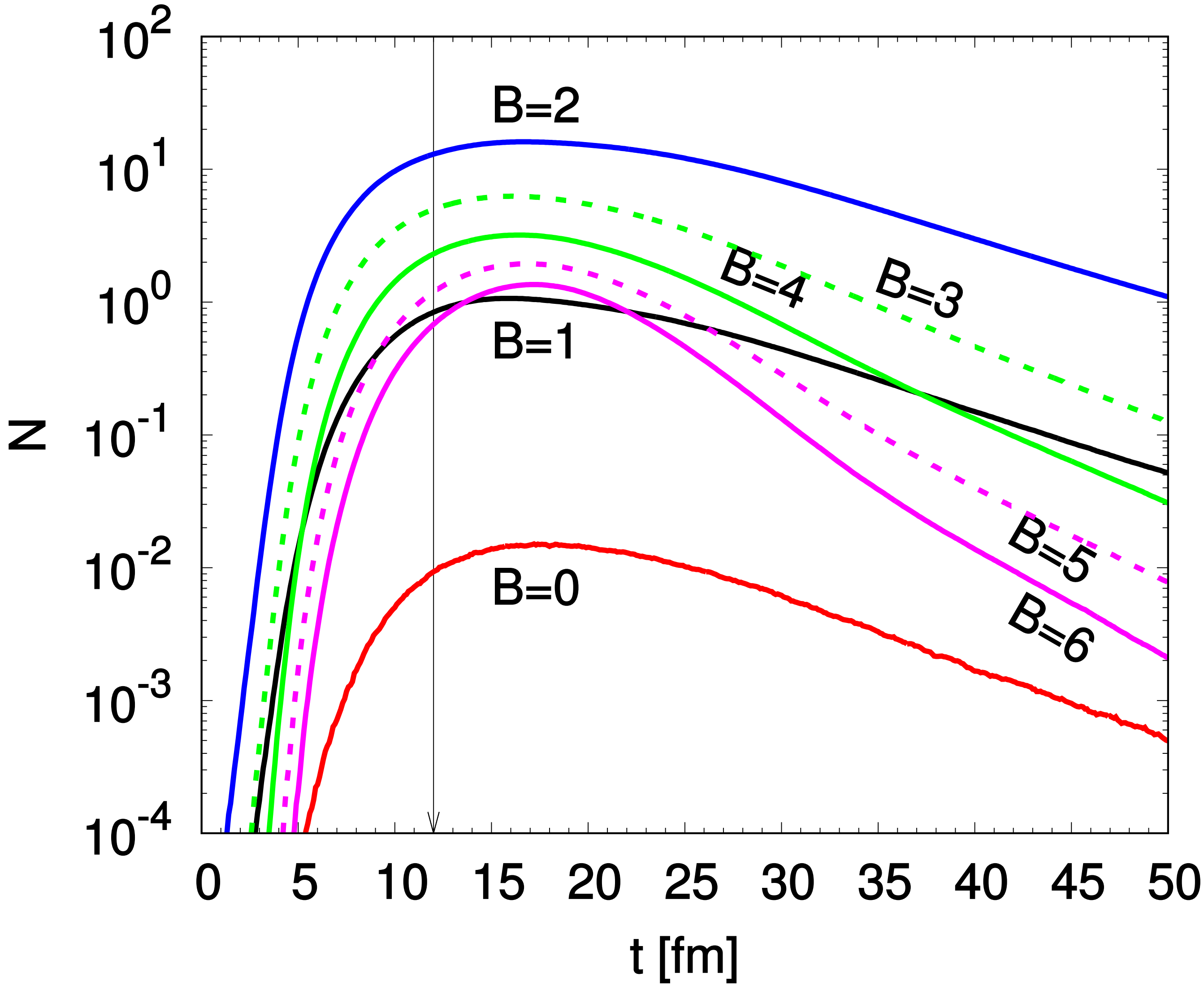
full dynamical calculation with Hagedorns in GiBUU



Au(1.23 AGeV)Au, 0-40%

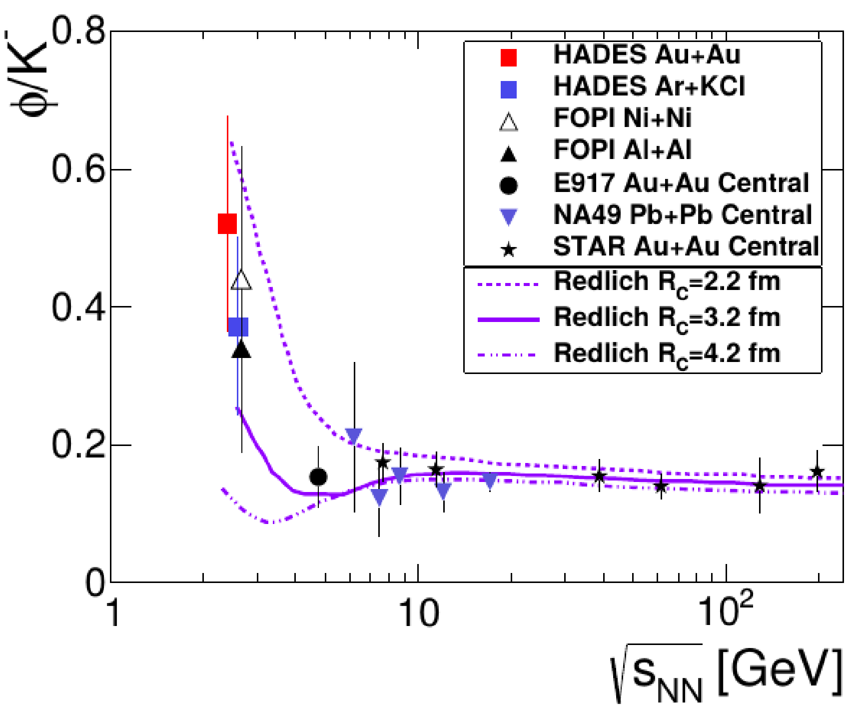
K.Gallmeister, M.Beitel, C.Greiner, PRC 98 (2018) 024915

- Hagedorn state multiplicity



phi/K-

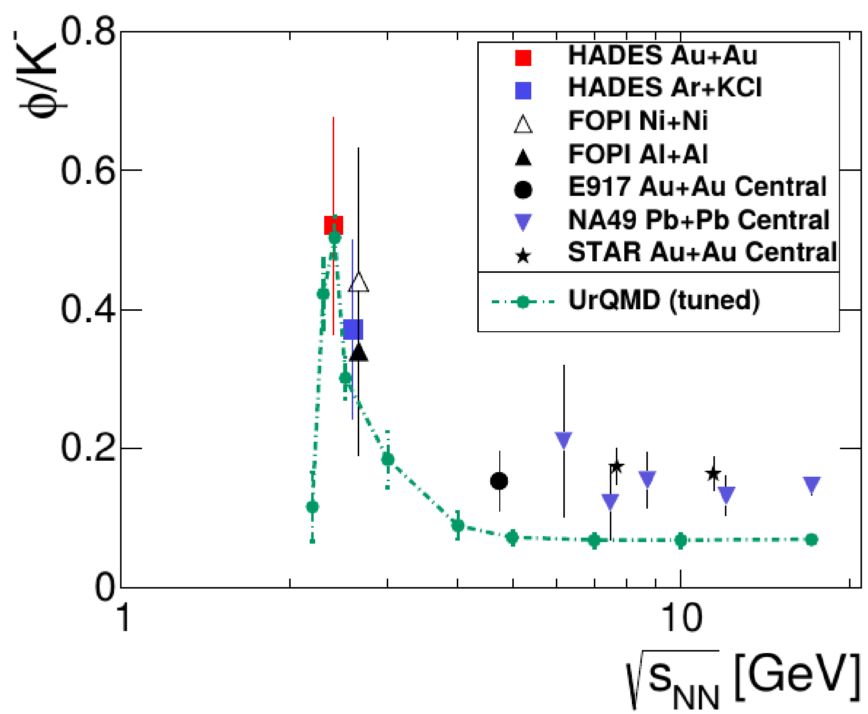
- statistical hadronisation, canonical strangeness suppression



H.Schuldes, PhD, 2016

- UrQMD + higher N* resonances

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



phi/K-

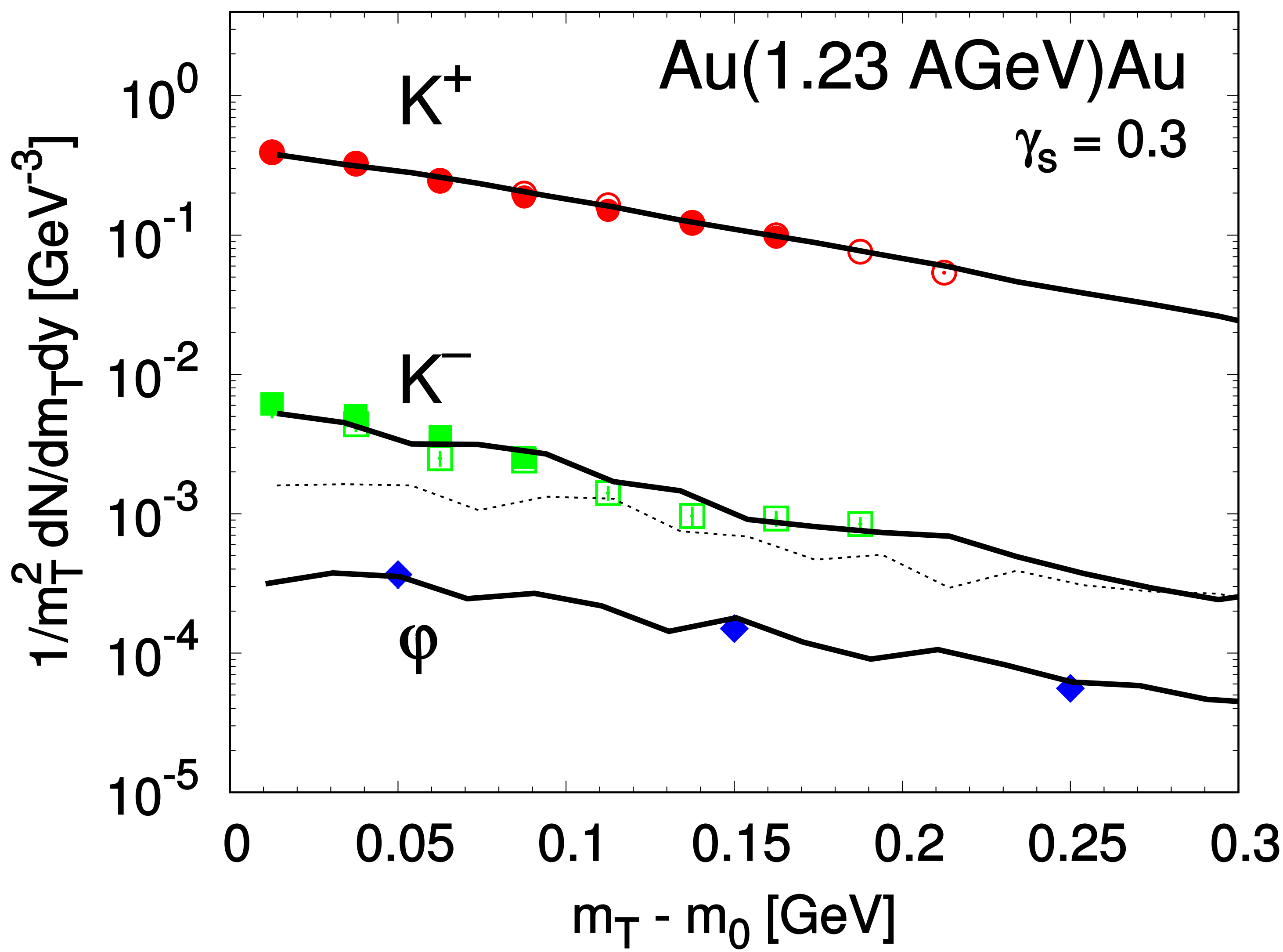
K.Gallmeister, M.Beitel, C.Greiner, PRC 98 (2018) 024915

	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

K.Gallmeister, M.Beitel, C.Greiner, PRC 98 (2018) 024915

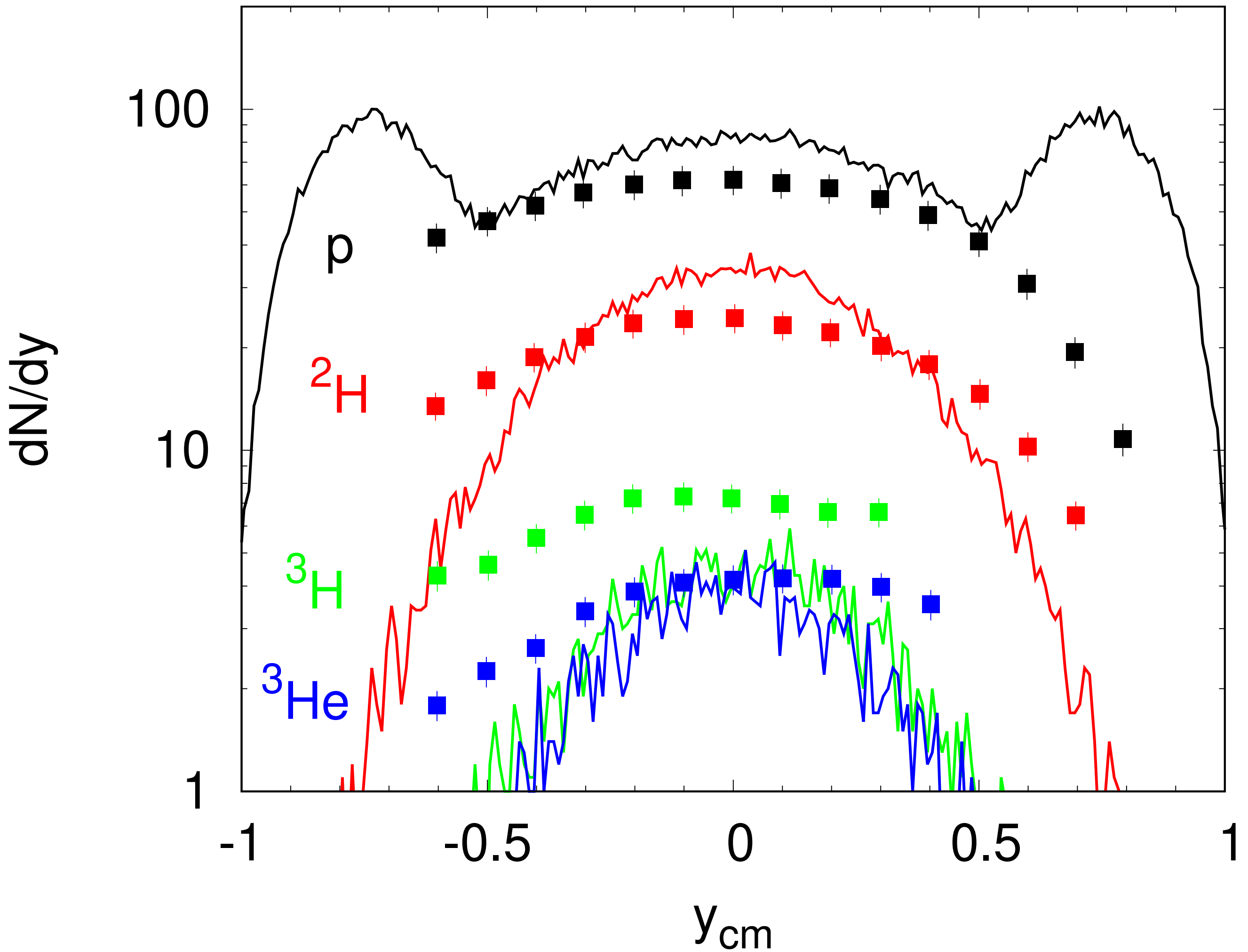


data: Adamczewski-Musch et al., PLB 778 (2018) 403

light nuclei

- rapidity spectra

data: Hades preliminary, M.Szala@Trento, Sept.2019



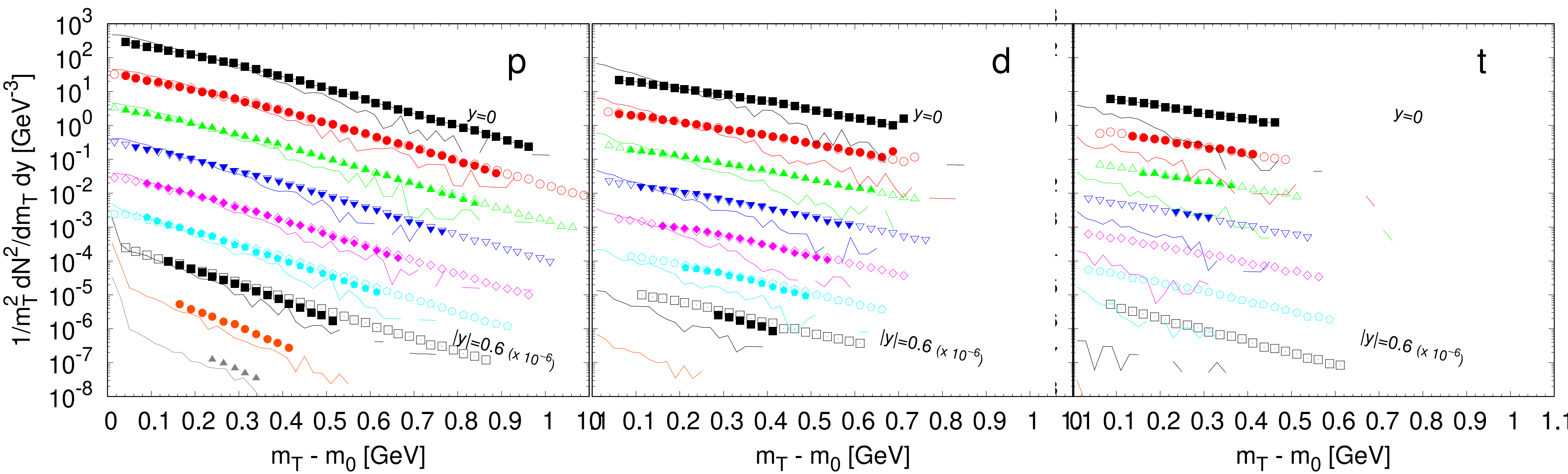
calculations:

- not enough stopping
- ^{3}H and ^{3}He identical

light nuclei

transverse momentum spectra

data: Hades preliminary, M.Szala@Trento, Sept.2019



calculations:

- not enough stopping
- ${}^3H$ and ${}^3He$ identical

conclusions

- Hagedorn state picture
  - consistent bootstrap from hadronic input
  - dynamical description (production, decay) via detailed balance
- light nuclei
  - inclusion straight forward, MC statistics problematic
  - single Hagedorn decay: does not explain ALICE data
  - Hagedorn gas: may explain ALICE data (large feed-down!)
- full dynamical calculations (HADES, Nica(?))
  - phi/K- ratio
  - light nuclei spectra (proton spectra!)
- near future: extension to charm sector
  - (BSI)→(BSCI), straight forward, numerically challenging (storage,time)