

A hadronic non-equilibrium interpretation of the K/π horn

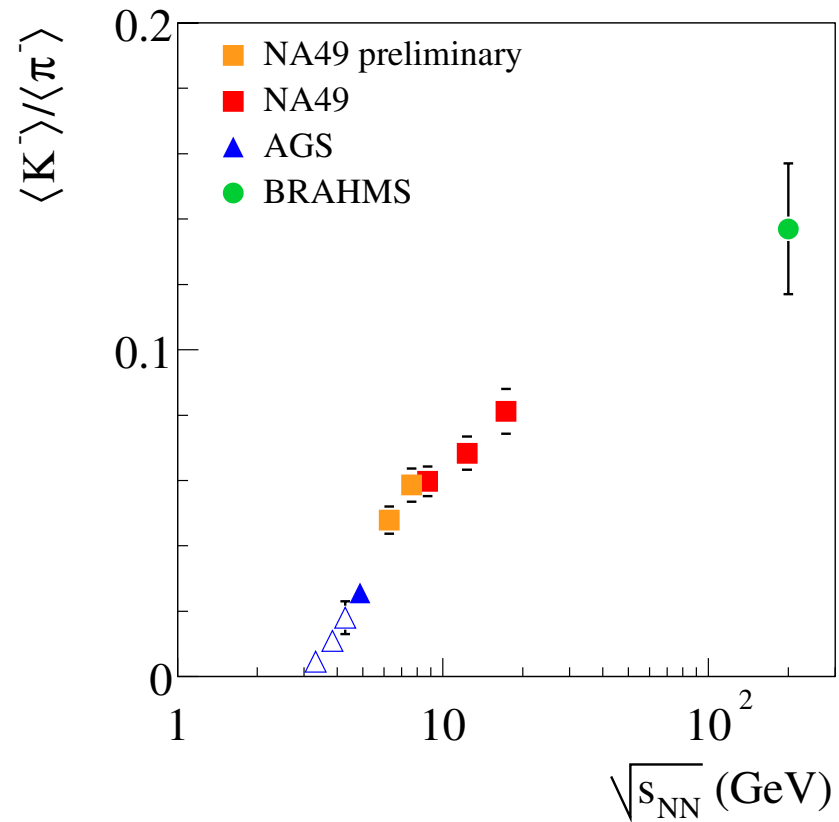
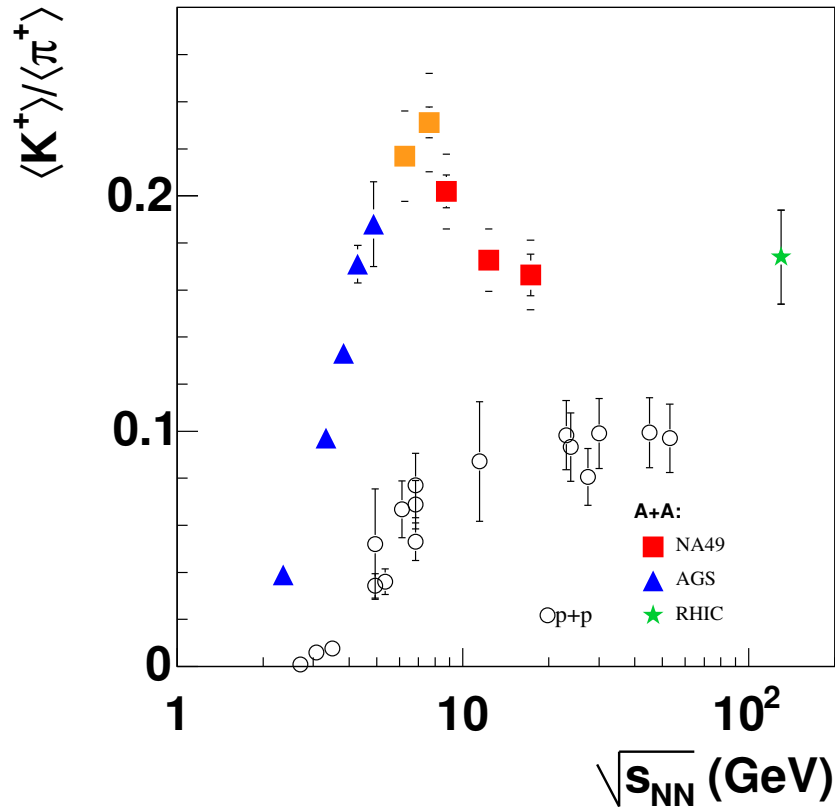
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work done in collaboration with E E Kolomeitsev

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1 Motivation: the horn



- Data: Benjamin Lungwitz [NA49], ISMD2005 proceedings [nucl-ex/0509041]

Motivation cont'd: theoretical understanding of the horn

- transport generators (RQMD, HSD) did not reproduce the horn
- 3-fluid hydro without QGP did not reproduce K^- (puzzling data?) [Ivanov, Russikh, Toneev]
- statistical models: less sharp maximum (talk by Andronic, many other)
- successful interpretation within SMES [Gaździcki & Gorenstein]
- successful kinetic calculation including QGP [Nayak et al., 2005]

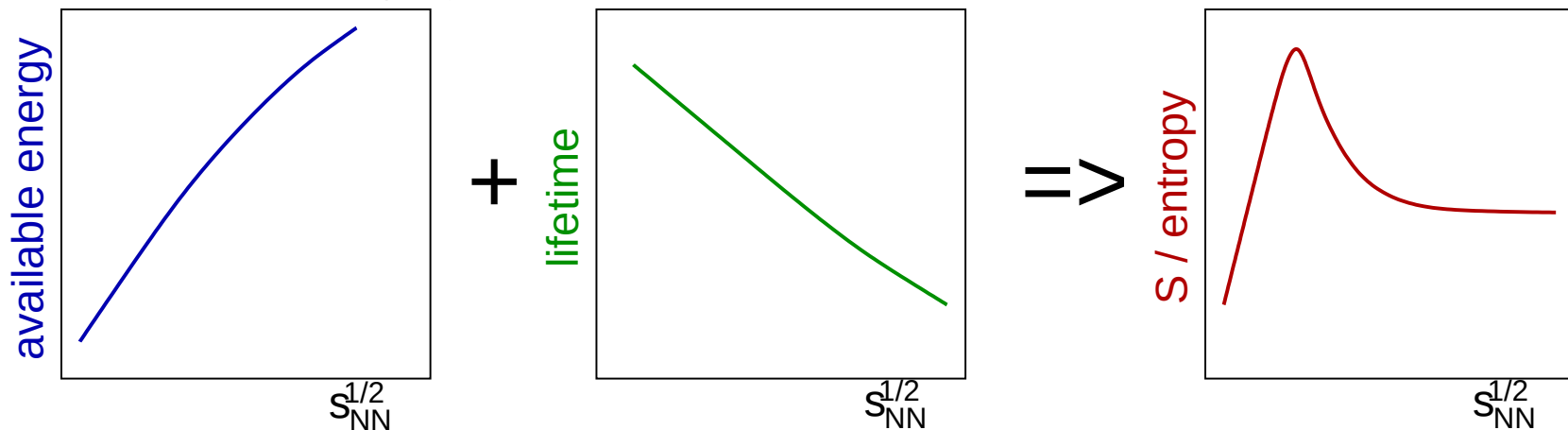
⇒ Do we really need a transition to non-hadronic d.o.f.?

2 Our approach

Two handles for the strangeness production:

- energy (density)
- total time

A cartoon of the working hypothesis:



- we try hadronic scenario; intrinsically assume non-equilibrium

Our approach: cont'd

- kinetic calculation with an ansatz for expansion
- similar to hydro-kinetic (flavor kinetic) calculations
- a little less similar to transport simulations

here: no attempt to calculate the space-time evolution

(which seems problematic in treatments currently on the market)

⇒ a data/experience (HBT, spectra) driven ansatz for expansion

- we want to explore various ansatzes and their impact on results

The model

- want to calculate **ratios** of yields $\rightarrow$ look at **densities** of species
- study **evolution** of the (kaon, pion, B, ...) **densities**

K^+ and K^0 evolution calculated from

$$\frac{dn_K}{d\tau} = \frac{d}{d\tau} \frac{N_K}{V} = -\frac{N_K}{V} \frac{1}{V} \frac{dV}{d\tau} + \frac{1}{V} \frac{dN_K}{d\tau}$$

$$\frac{dn_K}{d\tau} = n_K \left(-\frac{1}{V} \frac{dV}{d\tau} \right) + \mathcal{R}^+ - \mathcal{R}^-$$

expansion rate **production rate** **annihilation rate**
ansatz for this calculate from known cross-sections
and evolved densities

Production and annihilation

Calculation of densities:

- explicit **kinetic calculation**: K^+ , K^0 , K^{*+} , K^{*0} (vacuum properties)
- kaons in kinetic equilibrium (until decoupling)
- chemical equilibrium: non-strange species
- **relative** chemical equilibrium: $S < 0$ sector ($\bar{K}$, Λ , Σ , Ξ , Ω)
- no antibaryons assumed at these energies

Implemented K -production (**and annihilation**) rates:

$$\begin{array}{llll}\pi N \leftrightarrow KY, & \pi N \rightarrow NK\bar{K}, & \pi\Delta \leftrightarrow KY, & \pi\Delta \rightarrow NK\bar{K} \\ NN \rightarrow KNY, & NN \rightarrow NNK\bar{K}, & NN \rightarrow \Delta KY & \\ N\Delta \rightarrow NYK, & N\Delta \rightarrow NNK\bar{K}, & N\Delta \rightarrow \Delta KY & \\ \Delta\Delta \rightarrow \Delta YK, & \Delta\Delta \rightarrow NNK\bar{K} & & \\ \pi\pi \leftrightarrow K\bar{K}, & \pi\rho \leftrightarrow K\bar{K}, & \rho\rho \leftrightarrow K\bar{K}, & \pi\rho \leftrightarrow K\bar{K}^* \\ K^* \leftrightarrow K\pi, & \pi Y \leftrightarrow K\Xi, & & \end{array}$$

Ansatz for the expansion

$$\begin{aligned}\varepsilon(\tau) &= \begin{cases} \varepsilon_0(1 - a\tau - b\tau^2) & \tau < \tau_s \quad \text{acceleration} \\ \frac{\beta}{(\tau - \tau_0)^\alpha} & \tau > \tau_s \quad \text{power-law expansion} \end{cases} \\ n_{B,I}(\tau) &= \begin{cases} n_{0;B,I}(1 - a\tau - b\tau^2)^\delta & \tau < \tau_s \quad \text{acceleration} \\ \frac{\gamma}{(\tau - \tau_0)^{\alpha\delta}} & \tau > \tau_s \quad \text{power-law expansion} \end{cases}\end{aligned}$$

- explore a range of values for the model parameters
- at the end power-law scaling suggested by HBT
- this is a parametrisation “between Landau and Bjorken”

Initial and final conditions

- **initial** K^+ content estimated from pp (pn, nn) collisions
- initial $S < 0$ species balance strangeness and are relatively equilibrated

- we choose the initial ε_0 and the lifetime τ_T

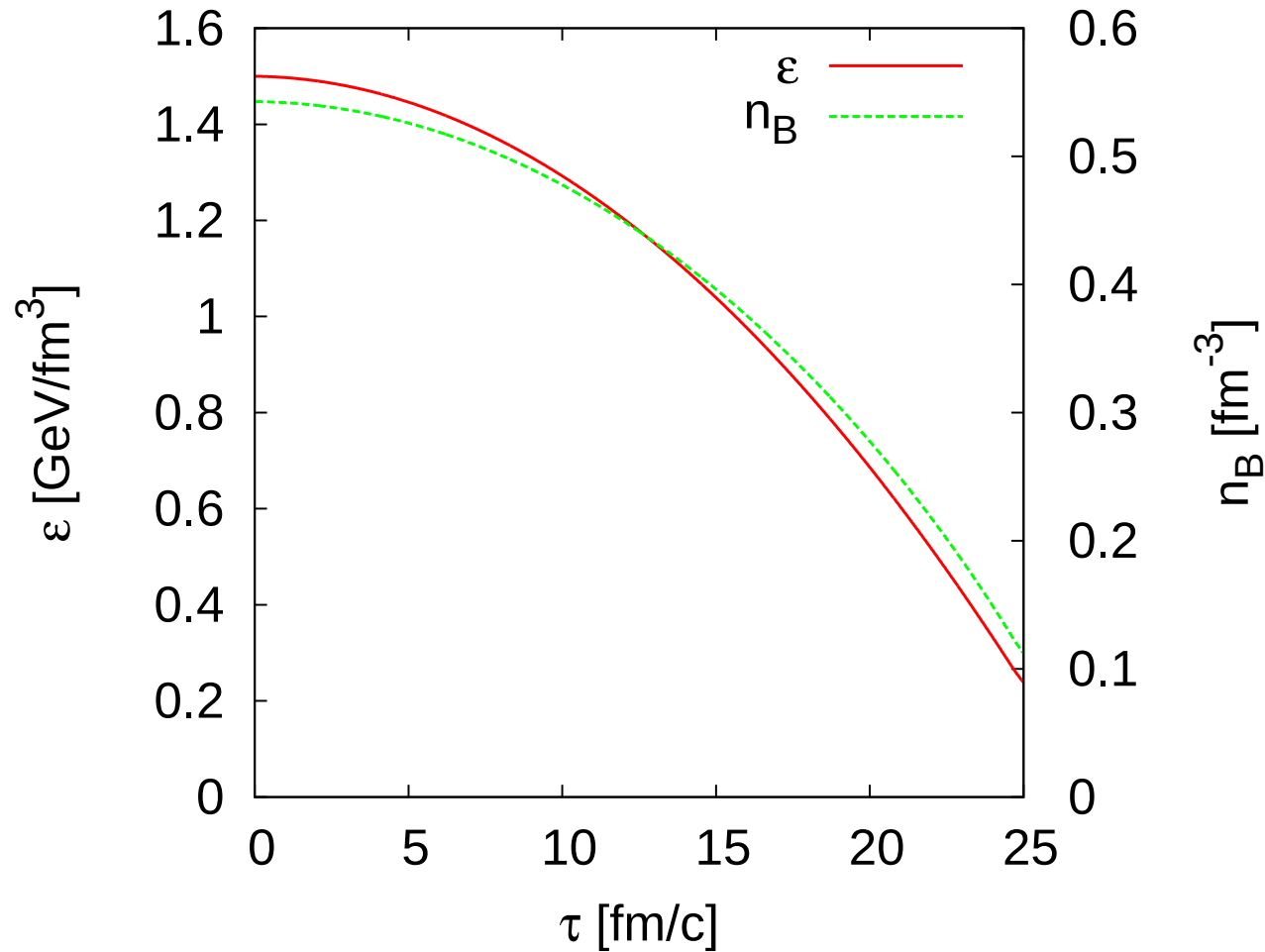
- fix the final state ε_{FO} , $n_{B,FO}$, $n_{3,FO}$

obtained from chemical FO analysis [Becattini et al., PRC **69** (2004) 024905]

$\Rightarrow$ we ceratianly end up with correct ε_{FO} , $n_{B,FO}$, $n_{3,FO}$, but temperature depend on strangeness production

$\Rightarrow$ for correct K^+ abundance $\Rightarrow$ correct T and $\mu_B \Rightarrow$ correct complete chemical composition

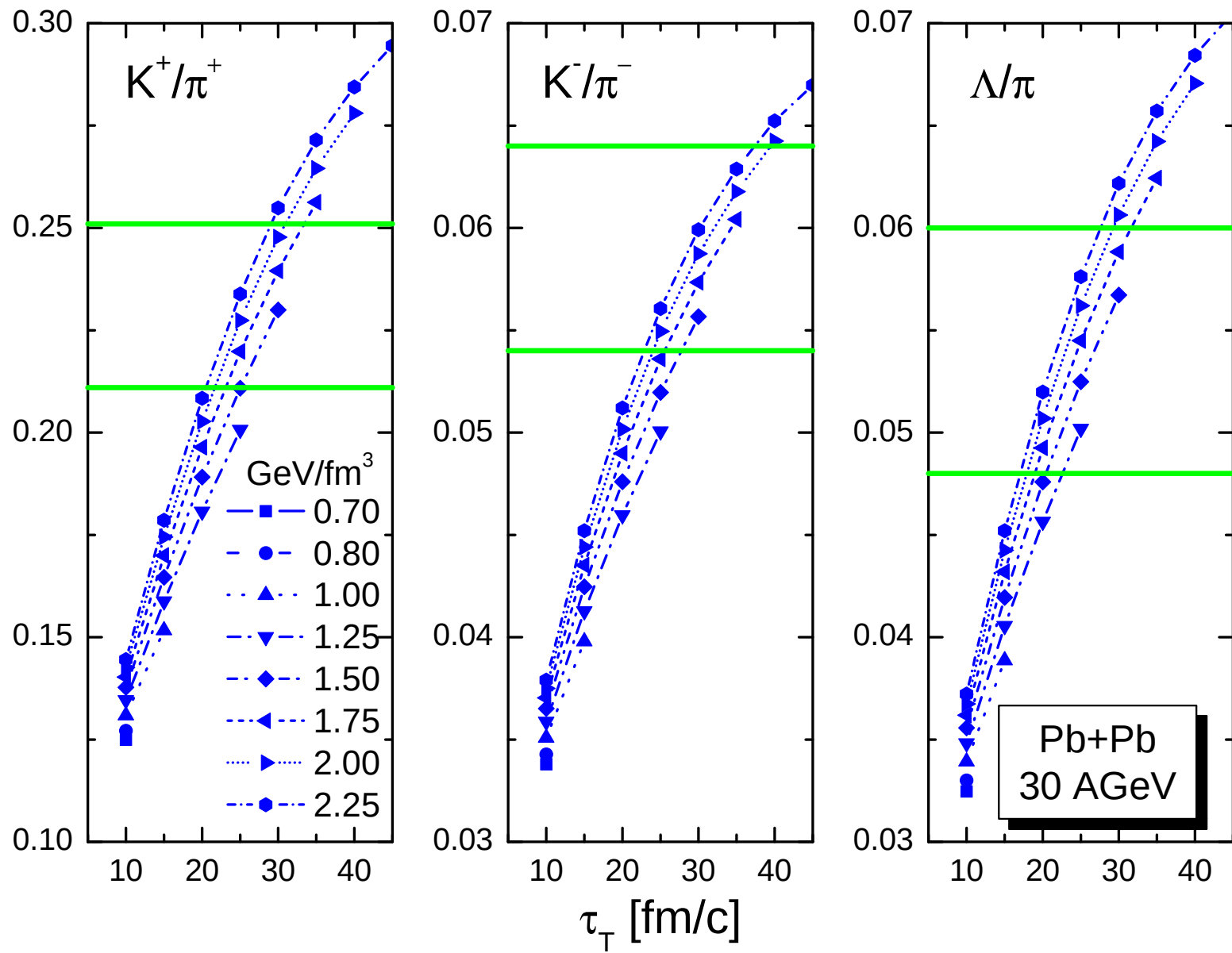
Example: time evolution of densities, here 30 AGeV scenario

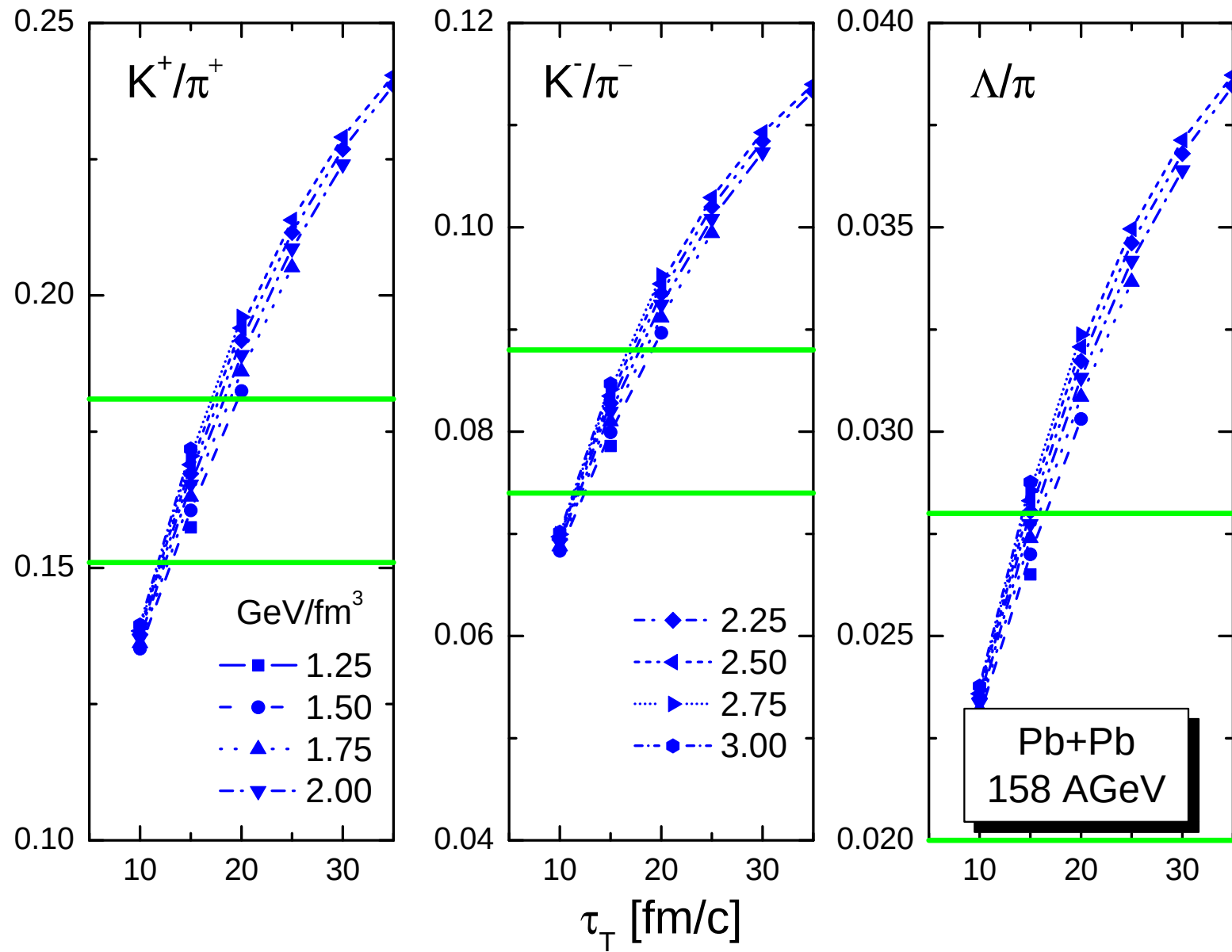


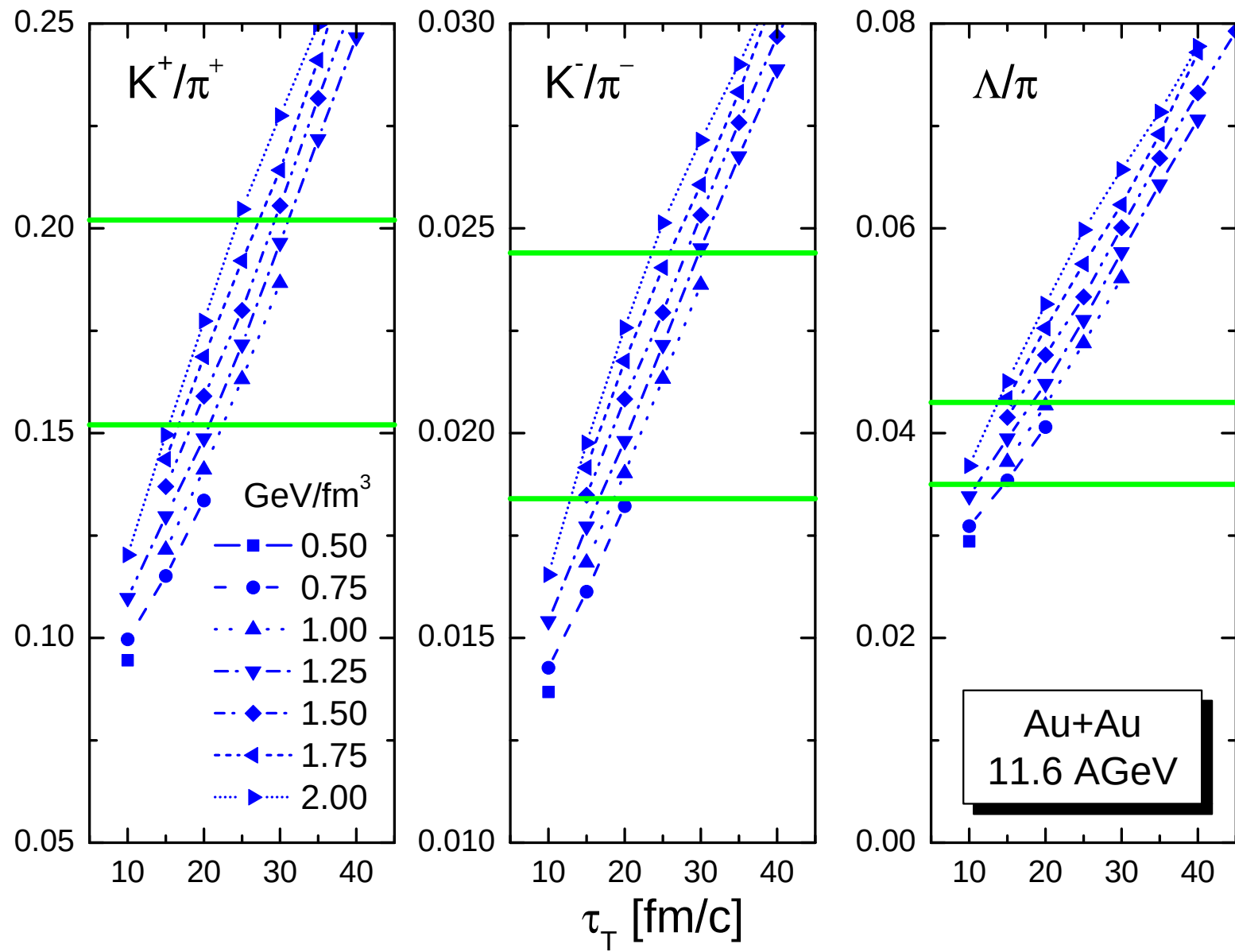
- the power-law prescription is realised only towards the end

How to control K^+ , K^- , and Λ production

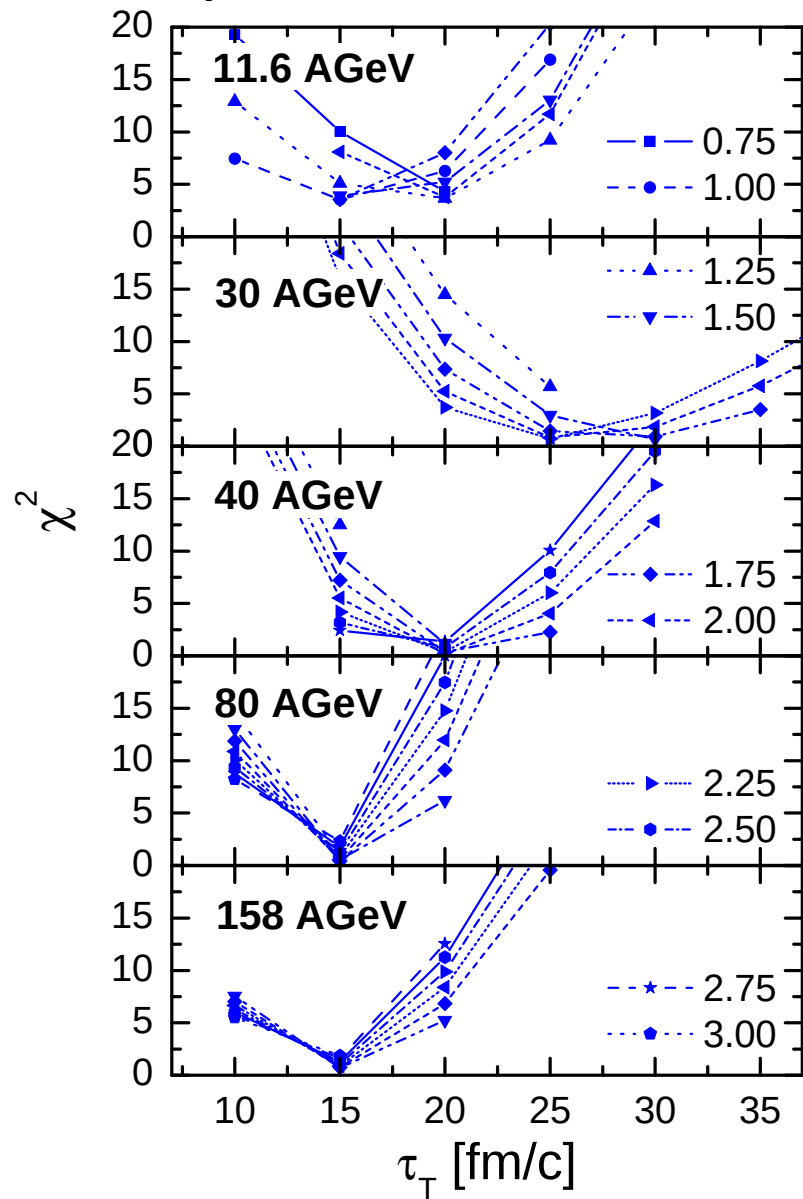
- density of $S > 0$ species (K^+ , K^0 , K^{*+} , K^{*0}) is controlled by **time** and also **temperature**
- density of $S < 0$ species must **balance** strangeness such that total strangeness of the system remains 0
- density of K^- **relative to** that of Λ is given by temperature and chemical potentials (relative equilibrium)







Summary of allowed lifetimes and initial energy densities



Plotted:

$$\chi^2 = \sum_{i=1}^3 \frac{(t_i - d_i)^2}{e_i^2}$$

t_i calculated value

d_i data value

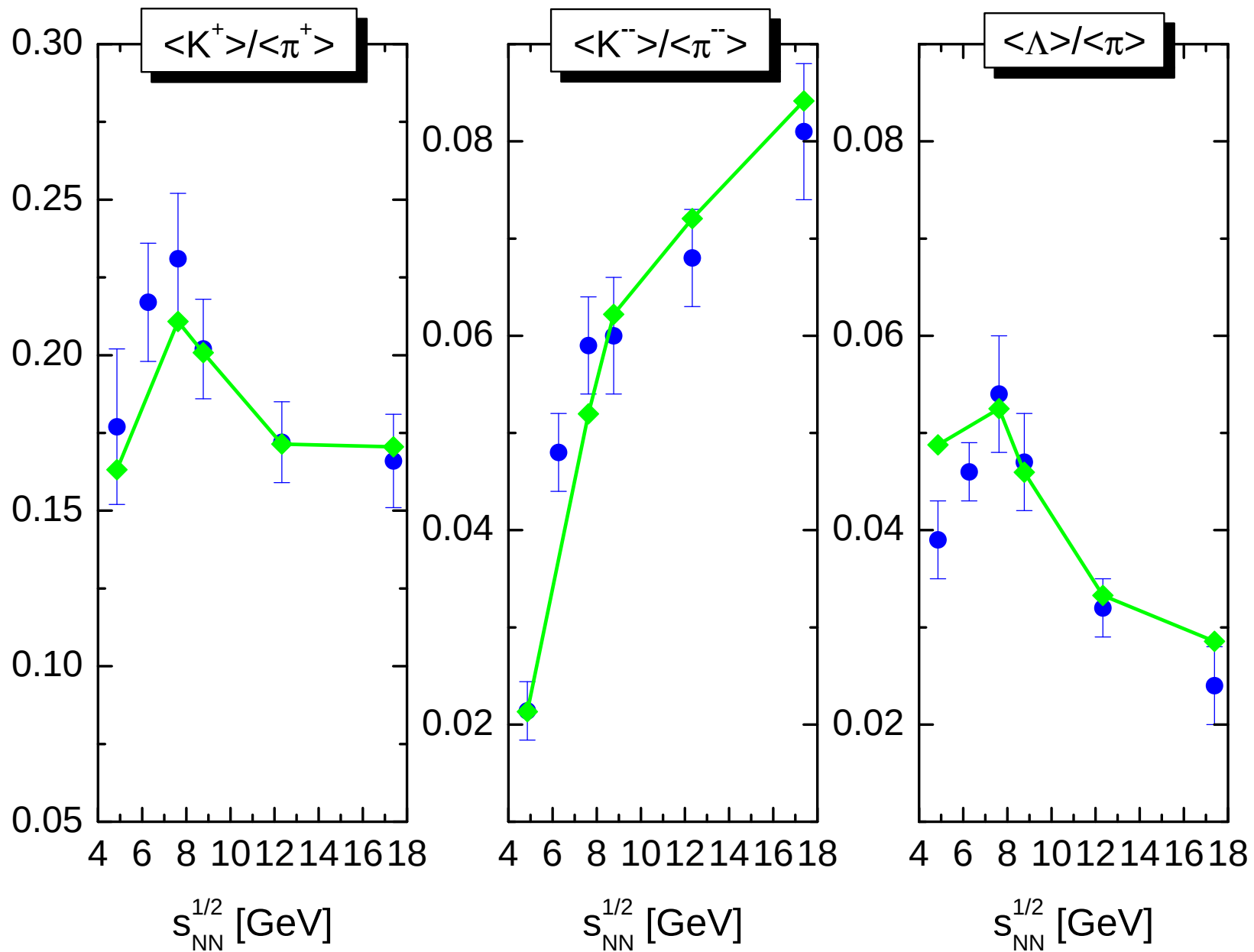
e_i error

Comparison to data

E_{beam} [A GeV]	11.6	30	40	80	158
ε_0 [GeV/fm ³]	1	1.5	2	2.25	2.75
τ_T [fm/c]	25	25	20	15	15
T [MeV]	118.1	139.0	147.6	153.7	157.8
T_f [MeV]	114.7	134.1	143.3	149.3	153.6

• our obtained temperature is close to that of Becattini et al.

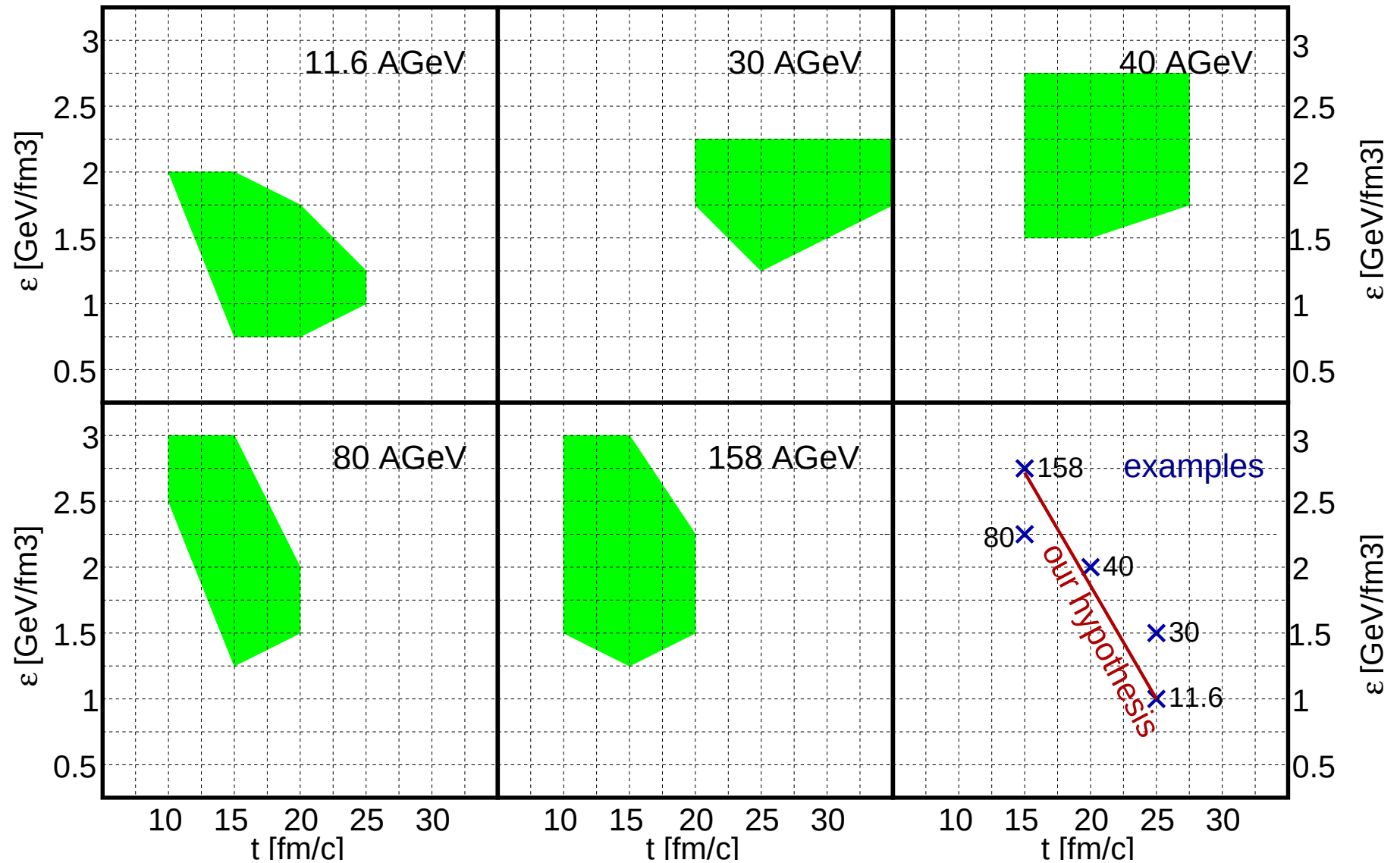
⇒ the whole final chemical composition is correct!



3 Conclusions

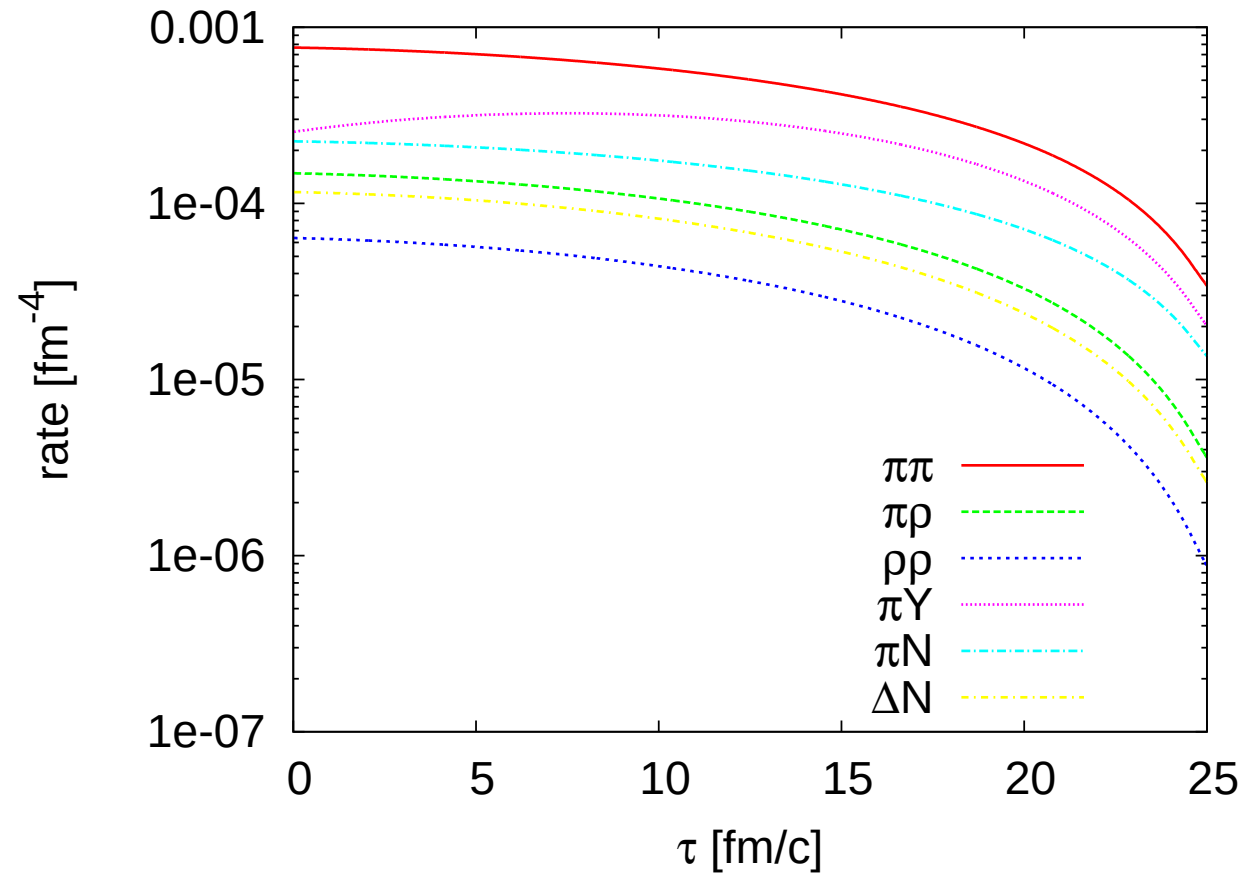
- hadronic non-equilibrium interpretation of $\sqrt{s_{NN}}$ dependence of strangeness production cannot be ruled out
- above the horn it requires decreasing total lifetime of the fireball as a function of beam energy
- this conjecture should be cross-checked with
 - careful analysis of kinetic and chemical freeze-out (spectra, HBT, abundancies)
 - dilepton spectra
 - ...
- the beam energy dependence of the lifetime needs to be explained microscopically or hydrodynamically

Summary of allowed lifetimes and initial energy densities

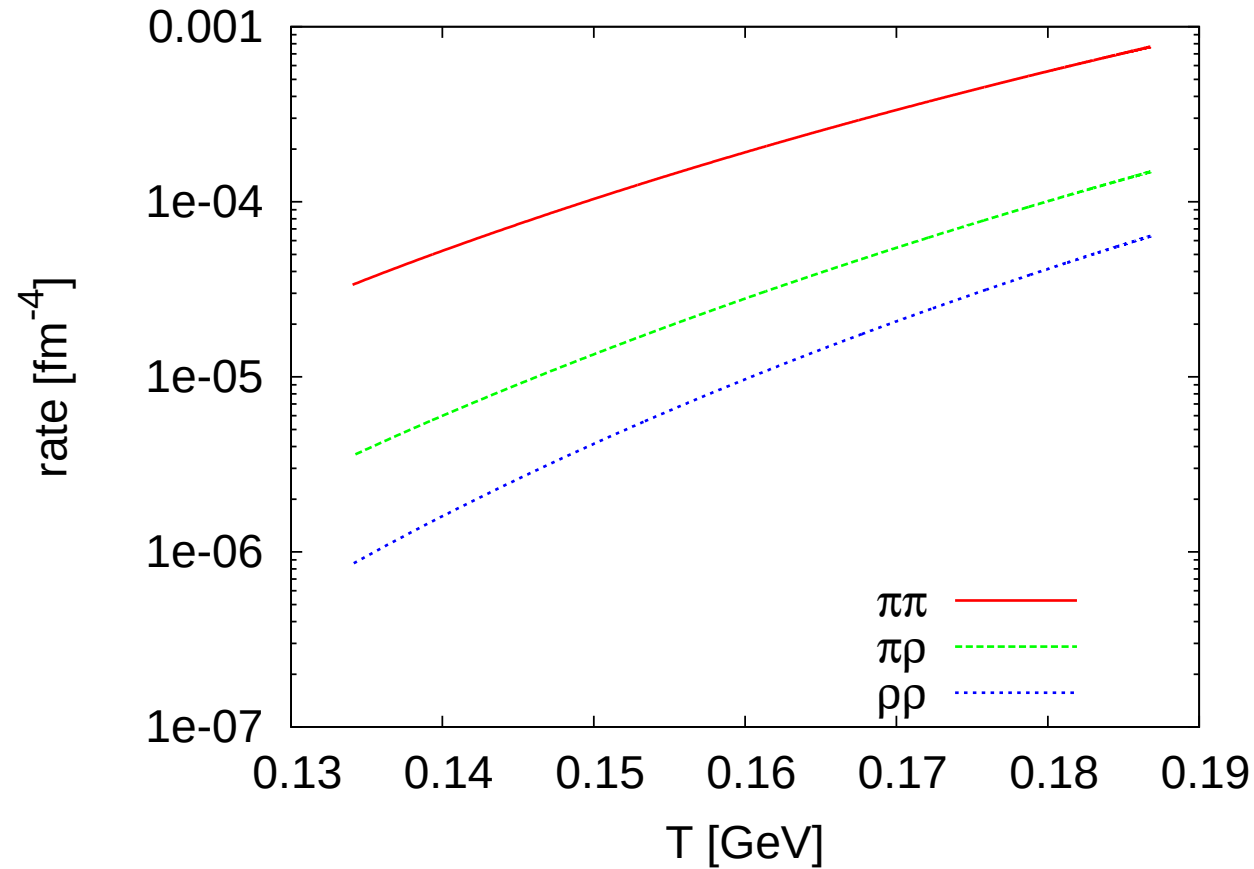


An overview of the production rates

- dominated by $\pi\pi$, πN , πY

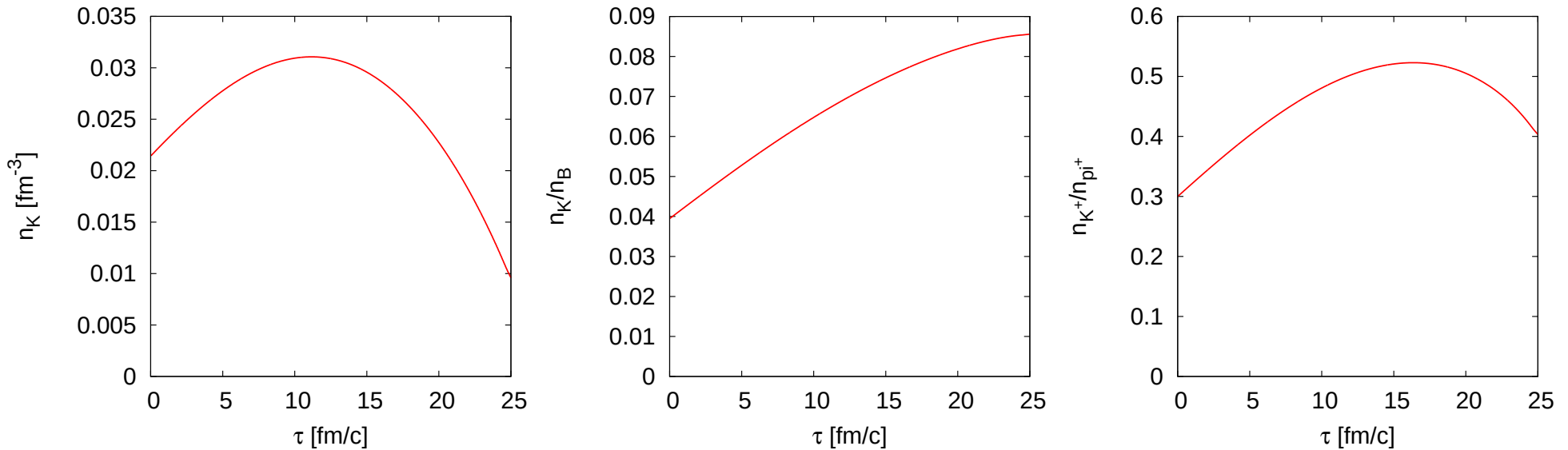


Comparison of $\pi\pi \rightarrow K\bar{K}$, $\pi\rho \rightarrow K\bar{K}$, $K\bar{K}^*$, $\rho\rho \rightarrow K\bar{K}$



- $\pi\rho \rightarrow K\bar{K}$ p -wave suppression, $\pi\rho \rightarrow K\bar{K}^*$ high threshold and thermal suppression
- $\rho\rho$ LO Weinberg-Tomozawa contact term
- (no medium modifications here)

Example: time evolution of K^+ density, scenario for 30 AGeV



- the decrease in K^+ density is due to expansion
- n_{K^+}/n_B shows the sole effect of kaon production
- n_{K^+}/n_{π^+} does not include resonance decay contributions