The K/π horn and the lifetime of the fireball

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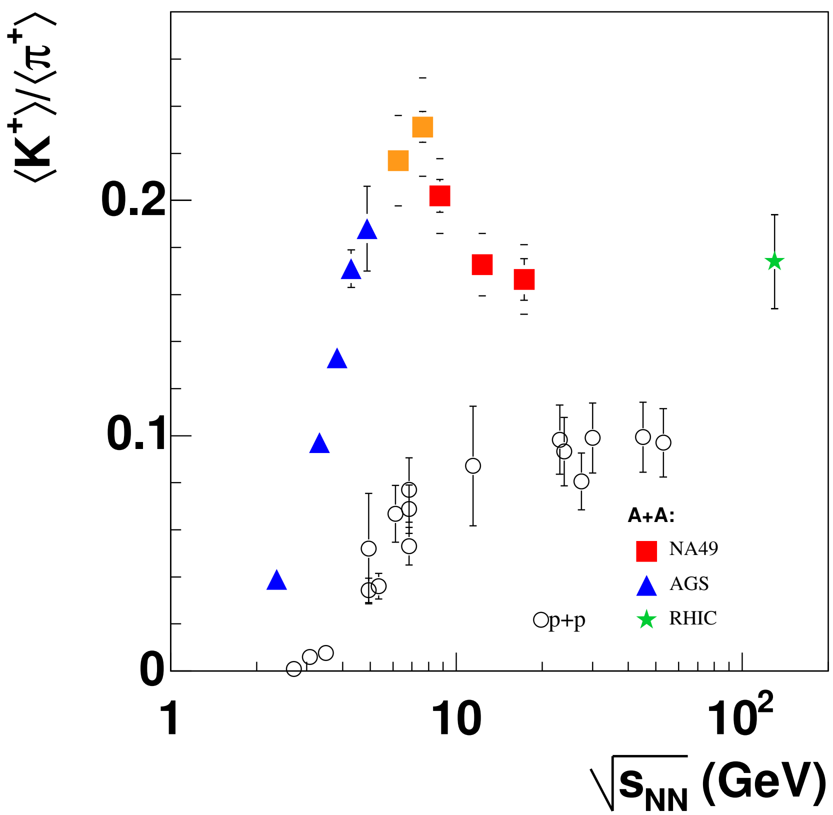
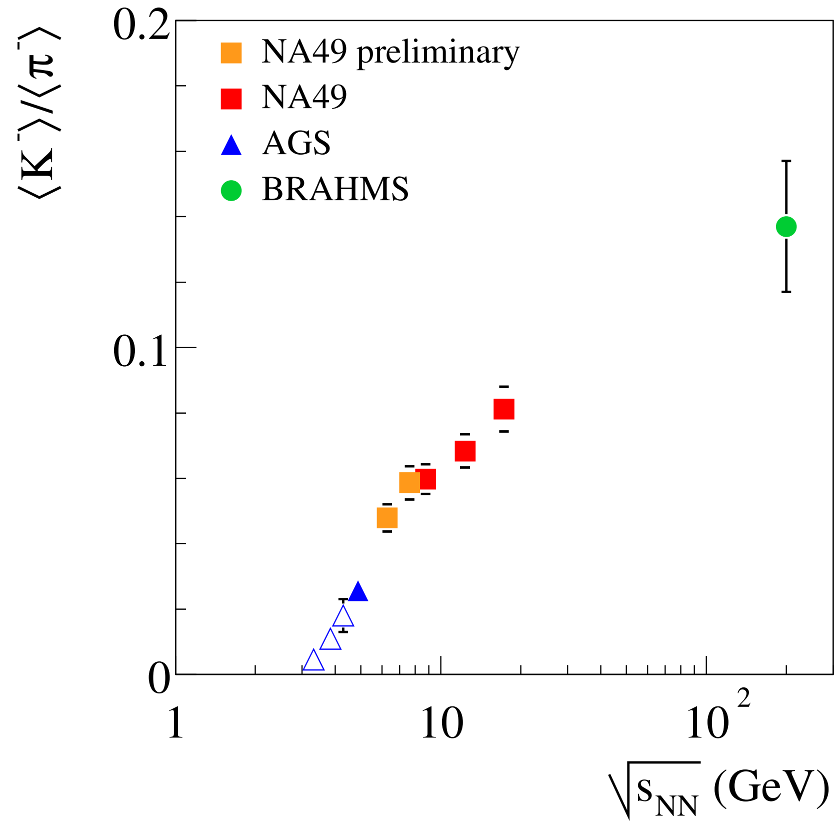
work done in collaboration with E E Kolomeitsev

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 [many names. . .]
- statistical model with γ_s: OK [Becattini et al.]
- successfull interpretation within SMES [Gaździcki & Gorenstein]
- successfull kinetic calculation including QGP [Nayak et al., 2005]

$\Rightarrow$ Do we really need a transition to non-hadronic d.o.f.?

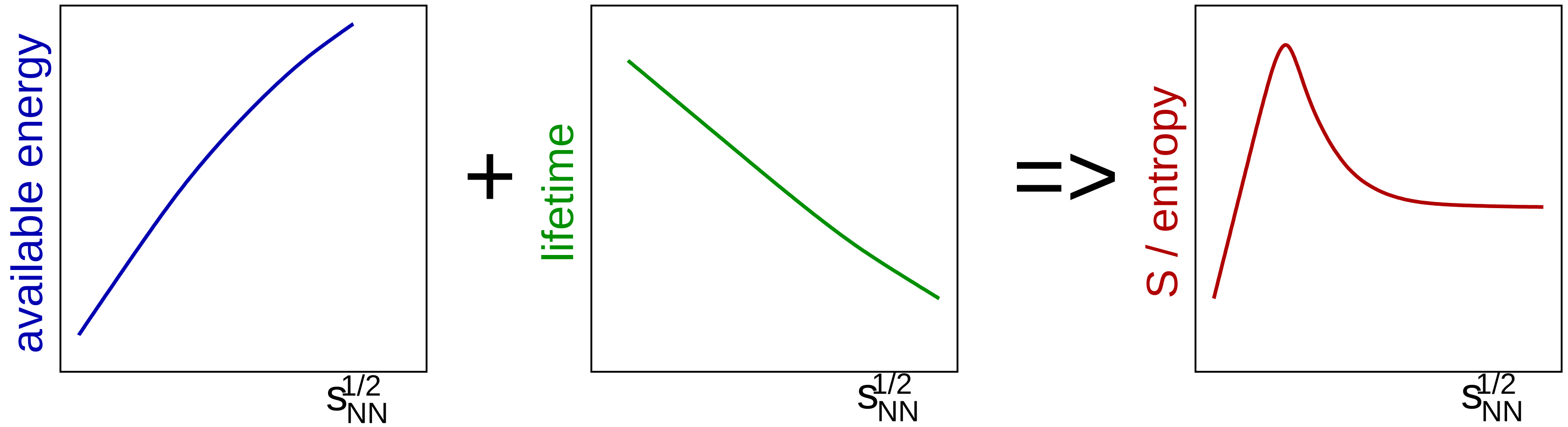
$\Rightarrow$ Can we explain/calculate γ_s?

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 chemical (strangeness) 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)

$\Rightarrow$ 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 $\longrightarrow$ look at densities of species
- study evolution of the kaon densities

K^+ and K^0 evolution calculated from

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

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

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:

- associated production $\pi N \leftrightarrow KY$, $\pi\Delta \leftrightarrow KY$
- meson-meson reactions ($\pi\pi$, $\pi\rho$, $\rho\rho$)
- K^* production and decay
- $\pi Y \leftrightarrow K\Xi$
- baryon-baryon reactions NN, $N\Delta$, $\Delta\Delta$

Ansatz for the expansion

- expansion implemented via behaviour of baryon number density

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

$$\varepsilon(\tau) = \begin{cases} \varepsilon_0(1 - a\tau - b\tau^2) & \tau < \tau_s \quad \text{acceleration} \\ \frac{\beta}{(\tau-\tau_0)^{\alpha}} & \tau > \tau_s \quad \text{power-law expansion} \end{cases}$$

- 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

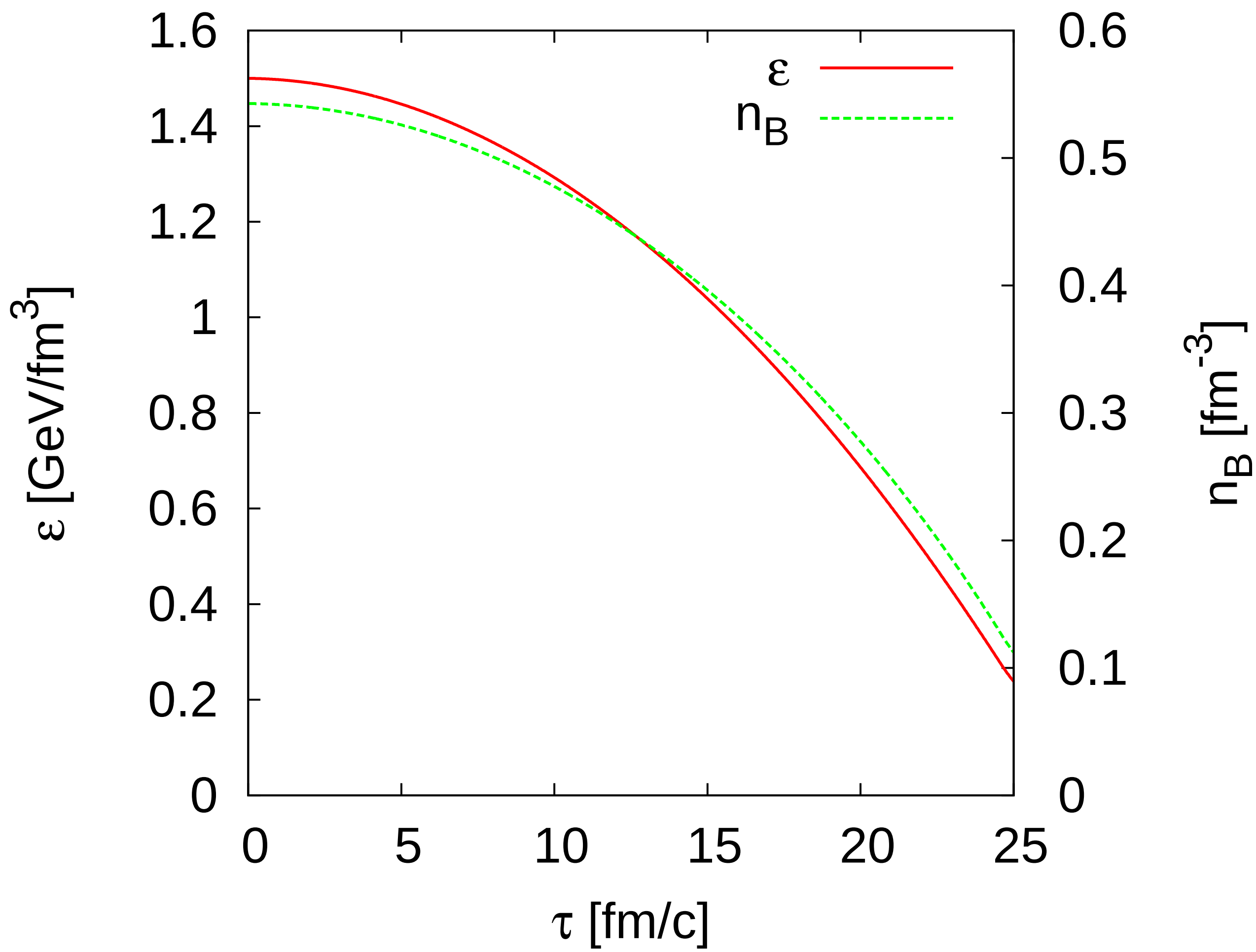
- fix the final state ε_{FO}, $n_{B,FO}$, $n_{3,FO}$

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

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

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

Example: time evolution of densities, here 30 AGeV scenario



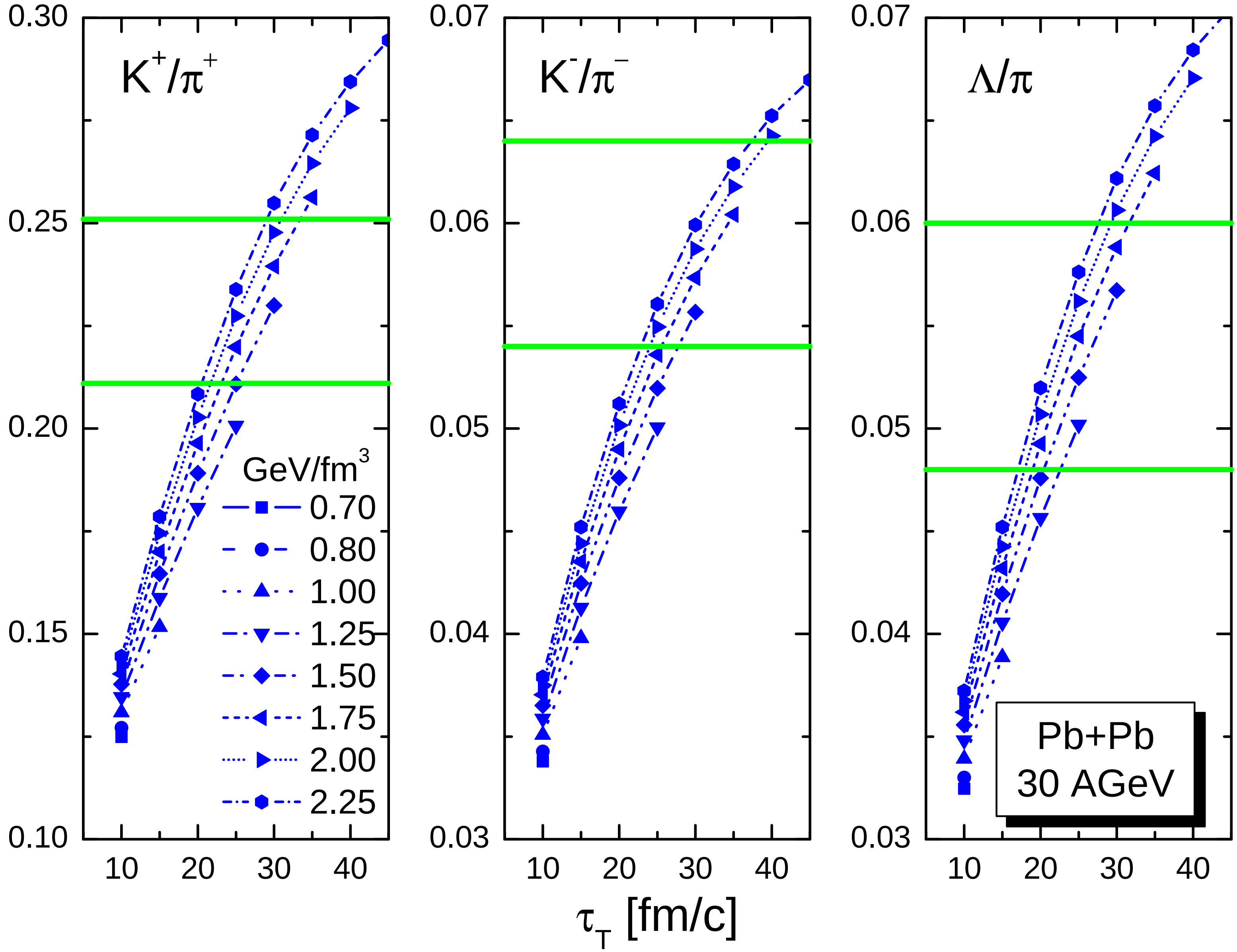
- the power-law prescription is realised only towards the end

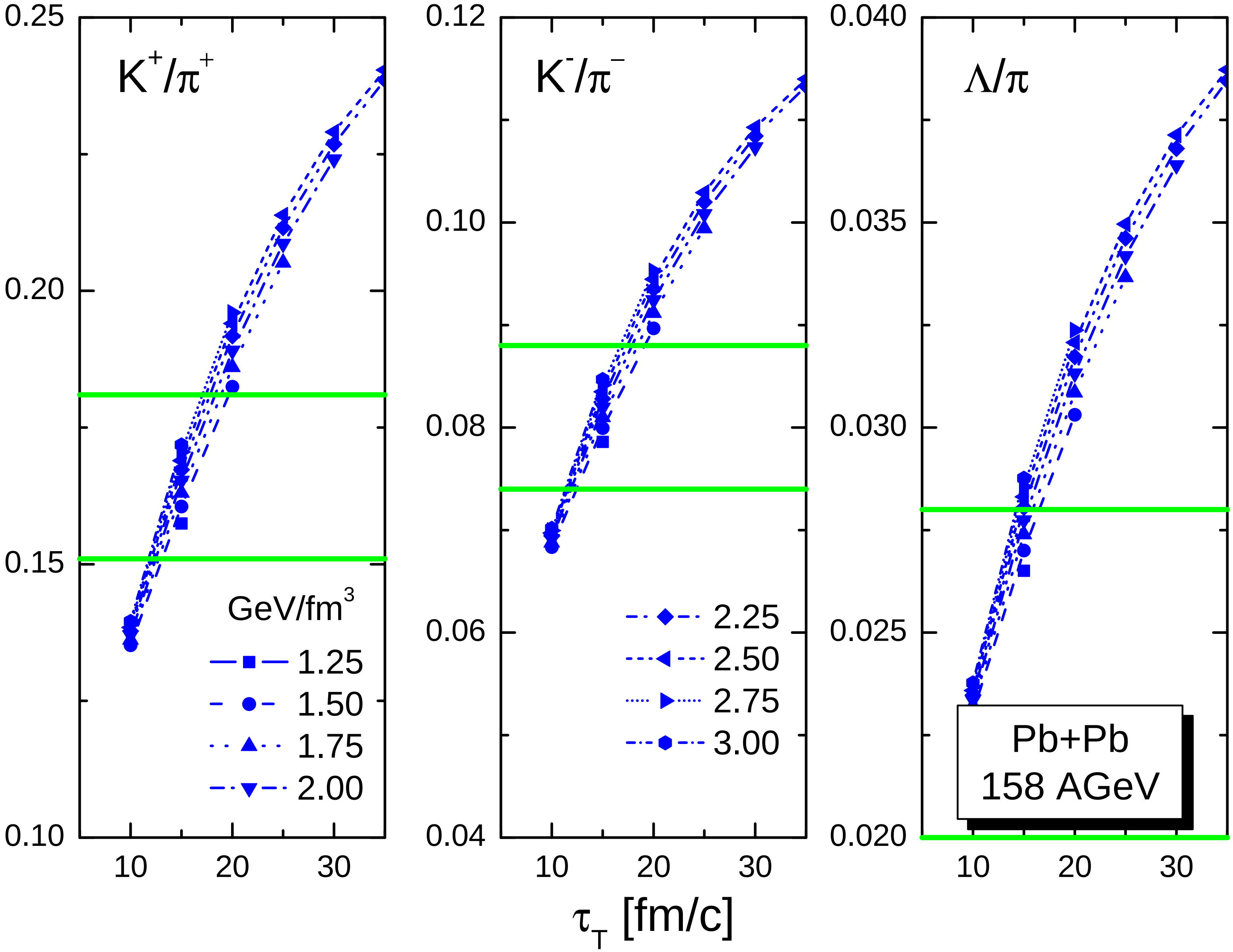
How to control K^+, K^-, and Λ production

- density of $S > 0$ species (K^+, K^0, K^{*+}, K^{*0}) is controlled by time and also temperature

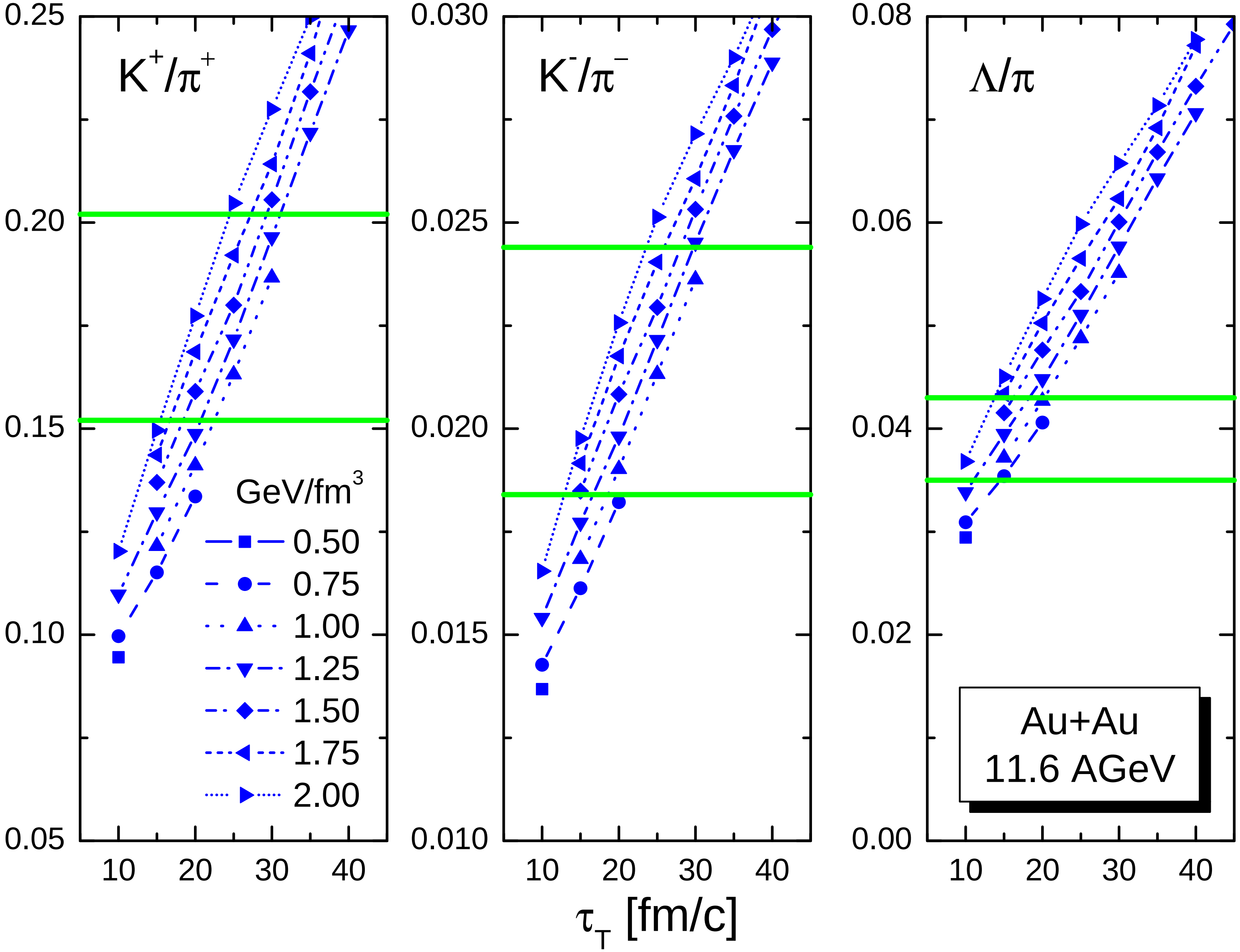
- density of $S < 0$ species must balance strangeness such that total strangeness of the system remains 0

- density of K^- relative to that of Λ is given by temperature and chemical potentials (relative equilibrium)


K+/π+
K-/π−
Λ/π
GeV/fm3
0.70
0.80
1.00
1.25
1.50
1.75
2.00
2.25
Pb+Pb
30 AGeV
0.30
0.25
0.20
0.15
0.10
0.07
0.06
0.05
0.04
0.03
10
20
30
40
τT [fm/c]

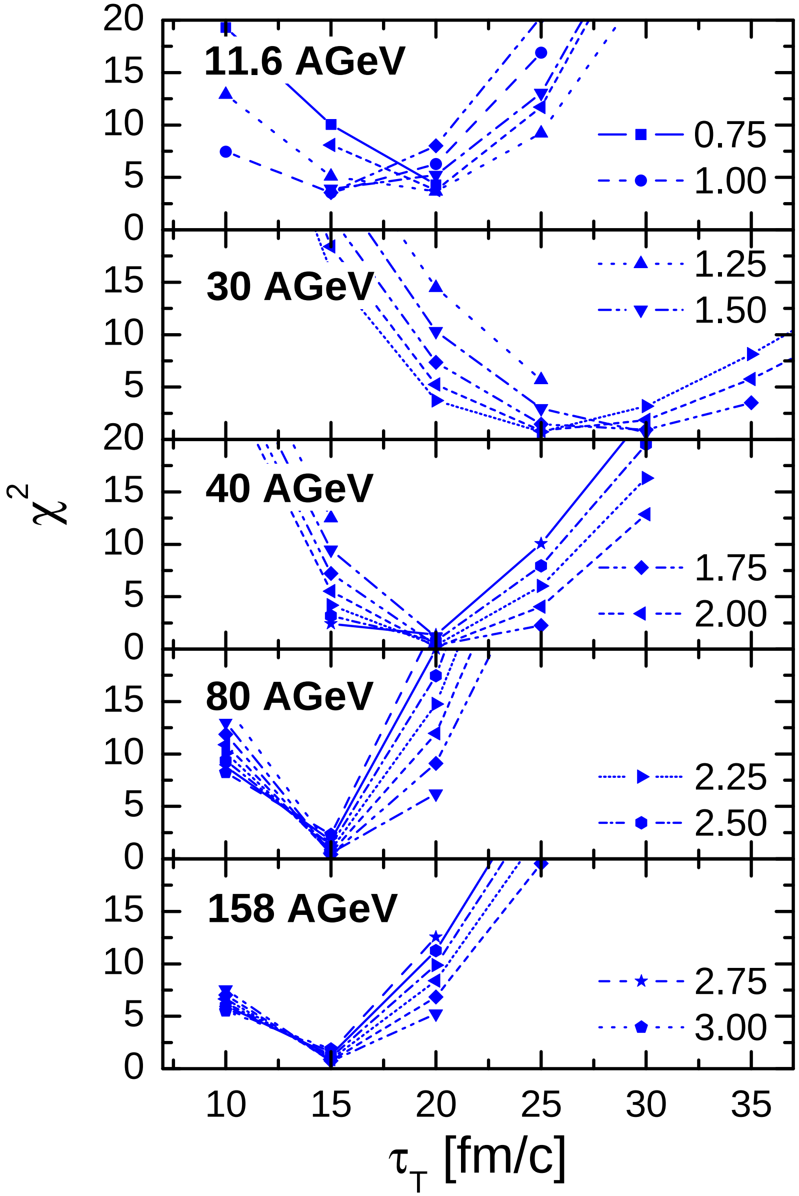


0.25
0.20
0.15
0.10
K^+/π^+
GeV/fm^3
1.25
1.50
1.75
2.00
10
20
30
0.12
0.10
0.08
0.06
0.04
K^-/π^-
2.25
2.50
2.75
3.00
0.040
0.035
0.030
0.025
0.020
Λ/π
Pb+Pb
158 AGeV
τ_T [fm/c]



K+/π+
K-/π−
Λ/π
GeV/fm3
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Au+Au
11.6 AGeV
τT [fm/c]
0.25
0.20
0.15
0.10
0.05
0.030
0.025
0.020
0.015
0.010
0.08
0.06
0.04
0.02
0.00
10
20
30
40

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

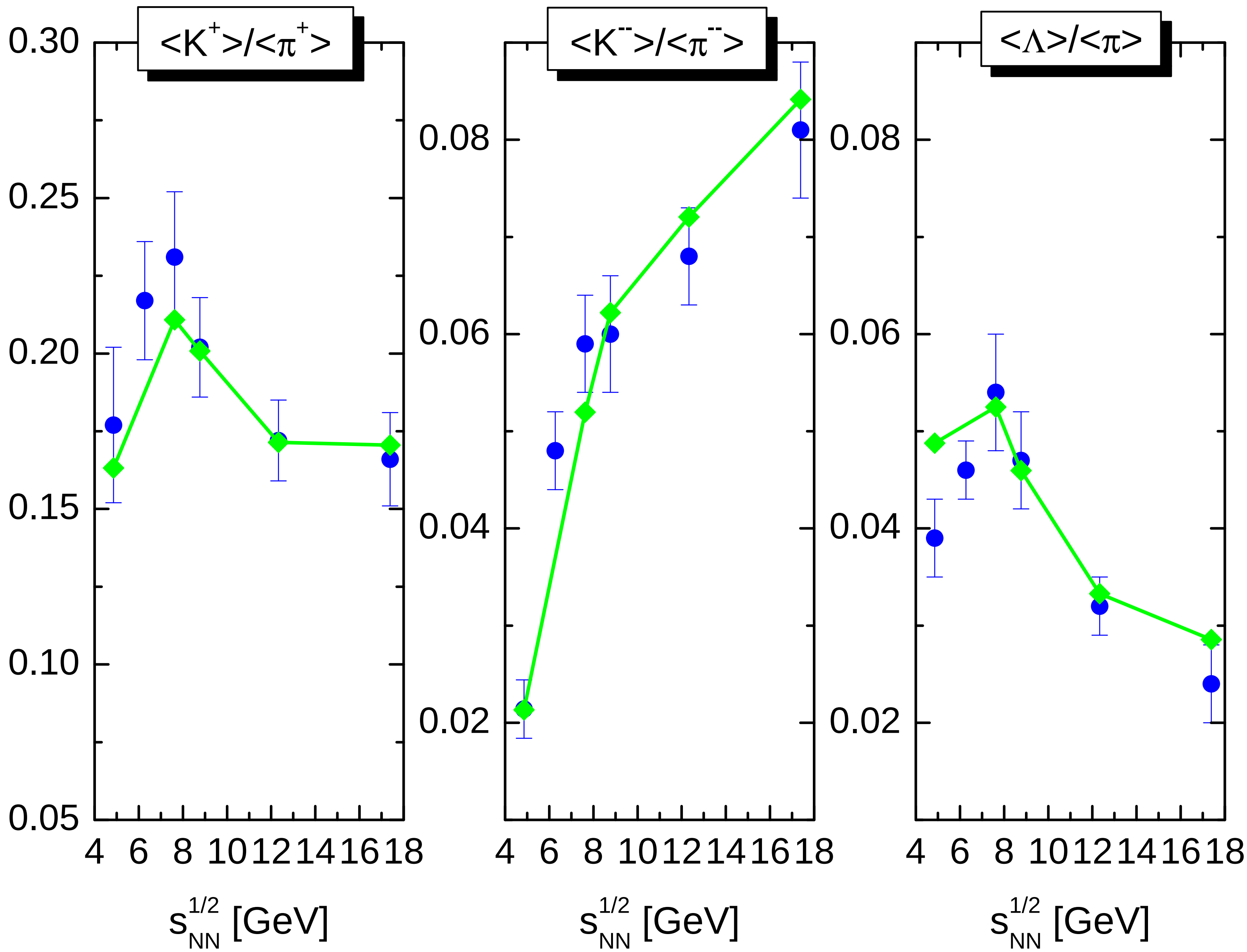
e_i error

Comparison to data

E_{beam} [AGeV]	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.

$\Rightarrow$ the whole final chemical composition is correct!



<K+>/<π+>
<K-->/<π-->
<Λ>/<π>
0.30
0.25
0.20
0.15
0.10
0.05
0.08
0.06
0.04
0.02
4 6 8 10 12 14 16 18
s_NN^1/2 [GeV]

3 Conclusions

• hadronic non-equilibrium interpretation of $\sqrt{s_{NN}}$ dependence of strangeness production cannot be ruled out

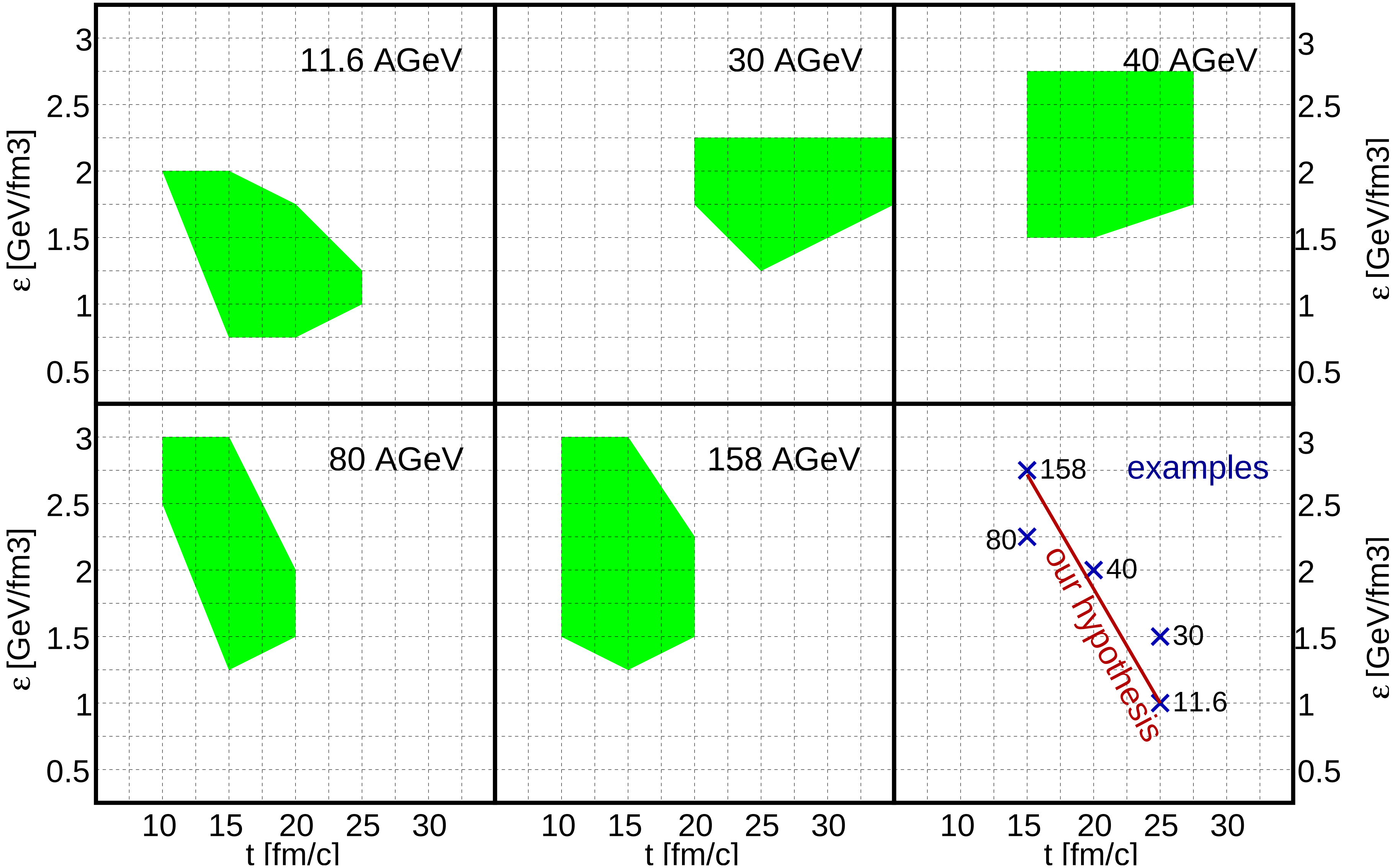
• above the horn it requires decreasing total lifetime of the fireball as a function of beam energy

• this conjecture should be cross-checked with

- careful analysis of kinetic and chemical freeze-out (spectra, HBT, abundancies)
- dilepton spectra
- ...

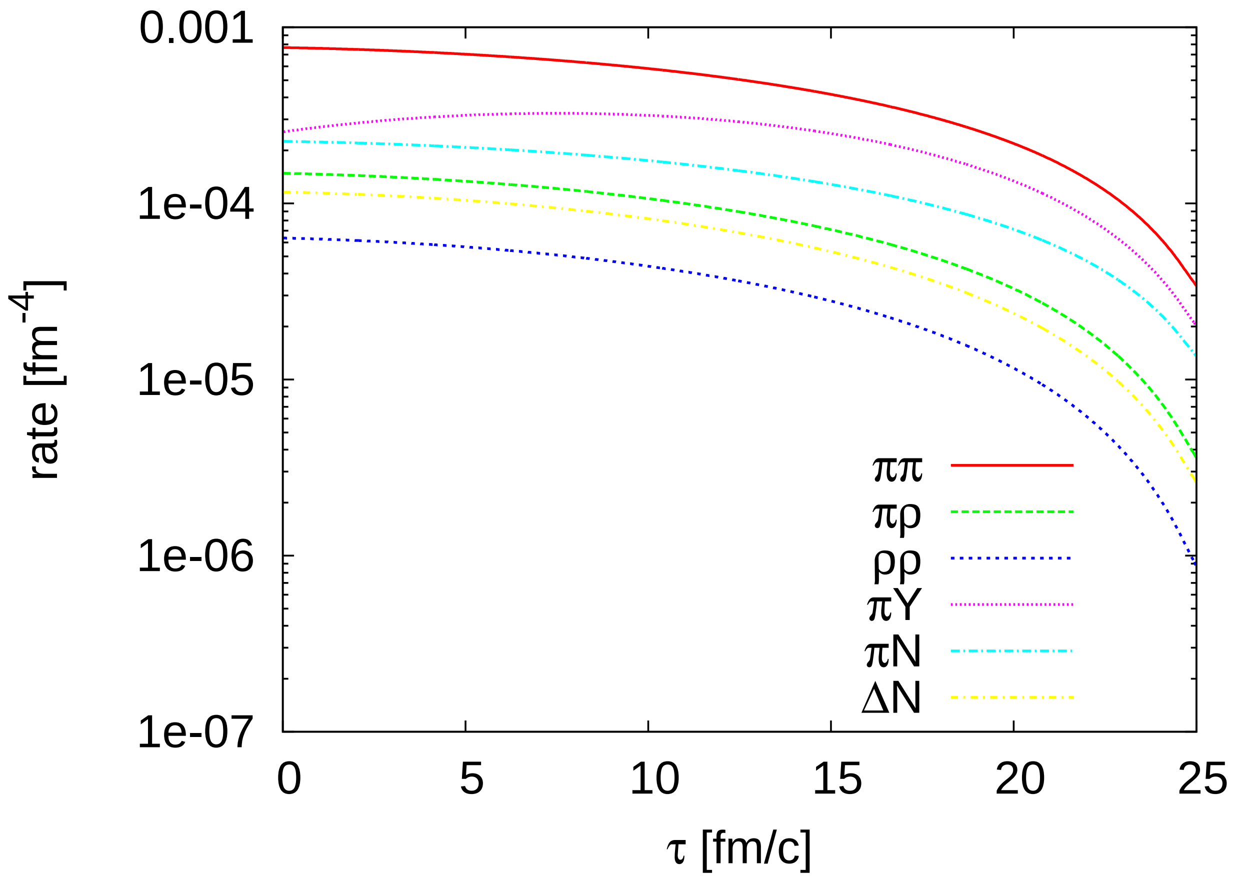
• the beam energy dependence of the lifetime needs to be explained microscopically or hydrodynamically

Summary of allowed lifetimes and initial energy densities

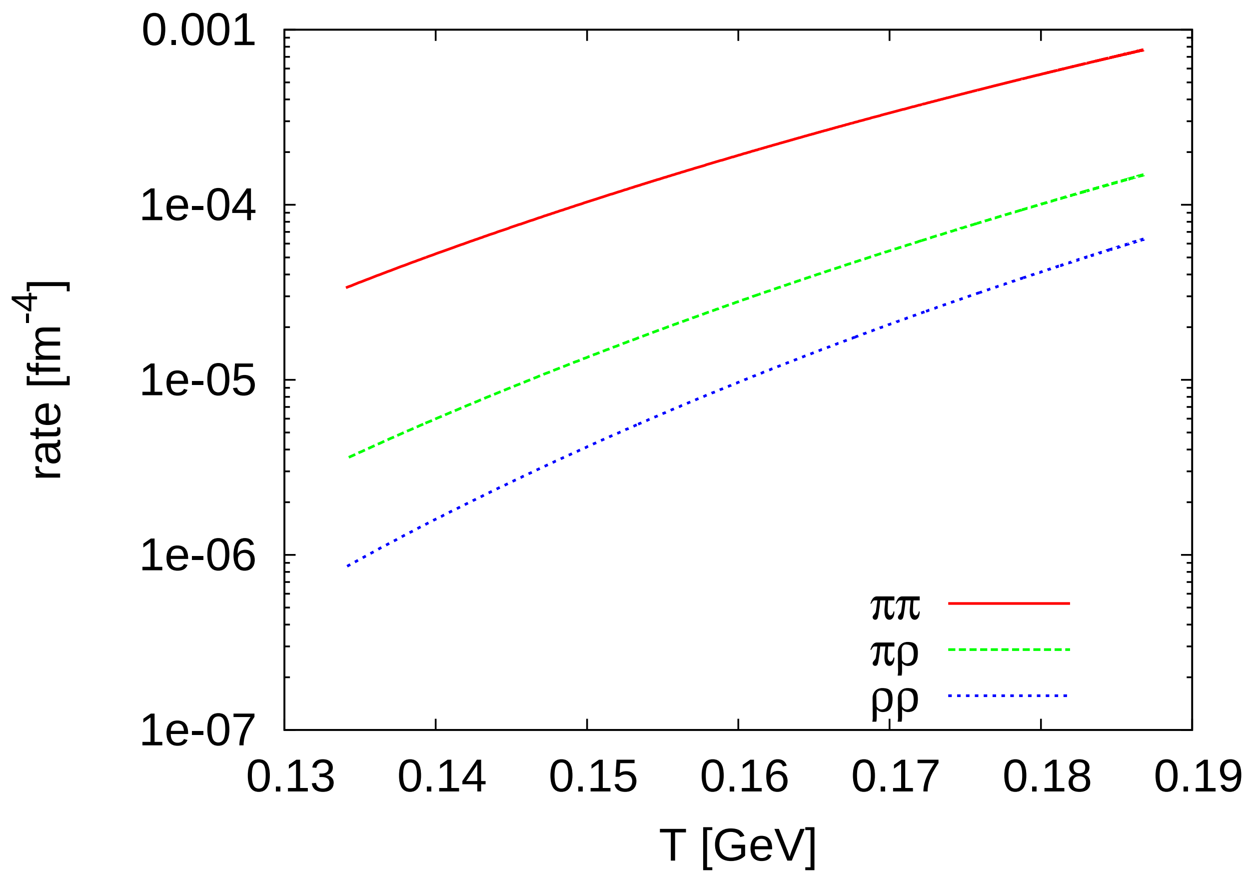


An overview of the production rates

- dominated by $\pi\pi$, πN, πY

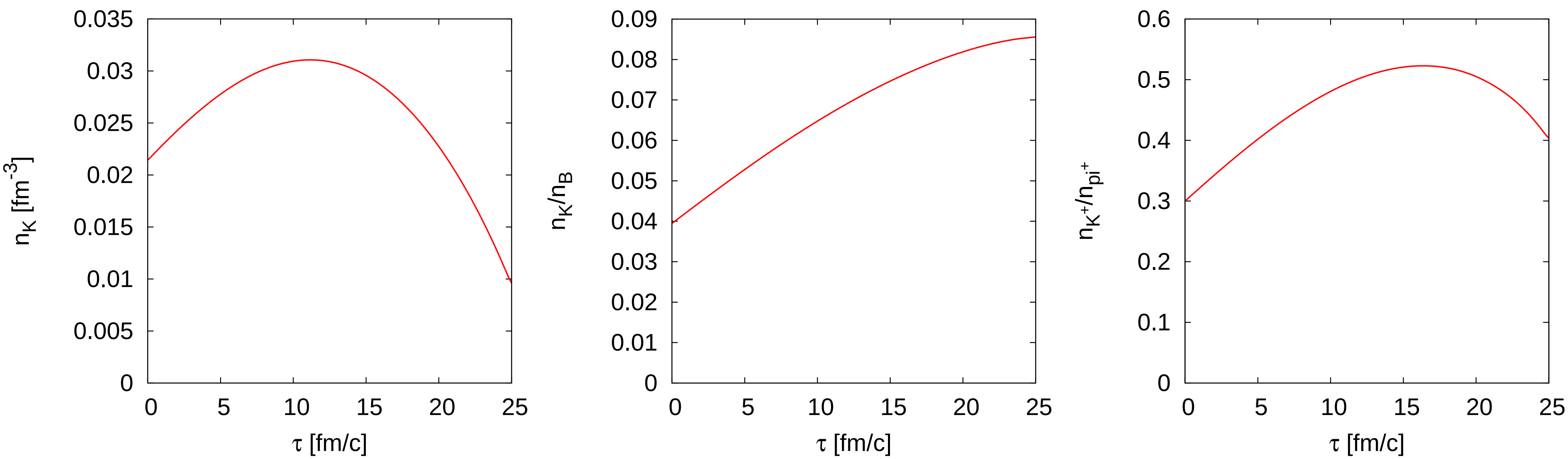


Comparison of $\pi\pi \to K\bar{K}$, $\pi\rho \to K\bar{K}$, $K\bar{K}^*$, $\rho\rho \to K\bar{K}$



- $\pi\rho \to K\bar{K}$ p-wave suppression, $\pi\rho \to K\bar{K}^*$ 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
- $n_{K+}/n_{\pi+}$ does <u>not</u> include resonance decay contributions