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Antihyperon-Production in Relativistic Heavy Ion Collisions

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QM2001, Stonybrook, January 15-20

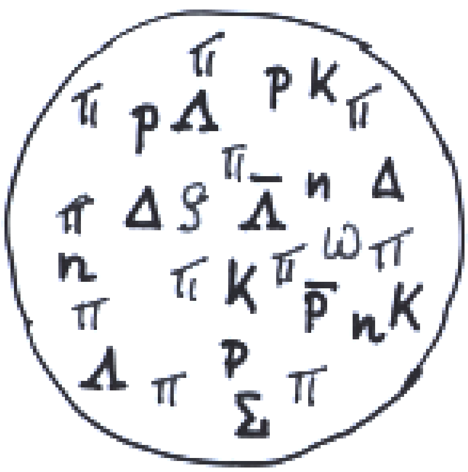
- ☐ Strangeness ... QGP ... why antihyperons?
- ☐ antihyperon production by *multi-mesonic* processes
- ☐ strangeness production in a hadronic transport model

Present status: experiment

- particle multiplicities → thermal state?

  ⇒ **Thermal Model of Hadron Resonance Gas**

  (Braun-Munzinger, Stachel)



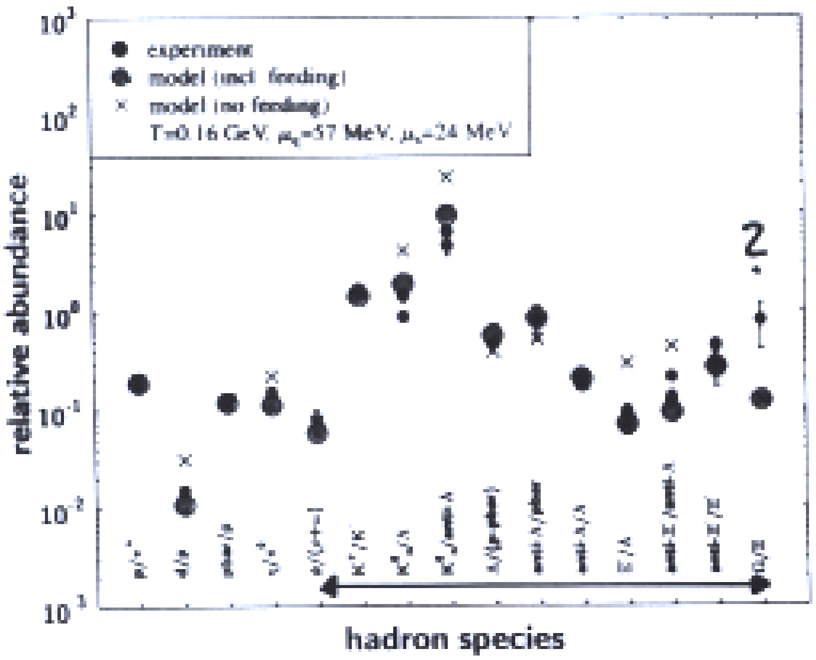
parameters:

T - temperature

$\mu_B = 3\mu_q$ - baryochemical potential

- assumption: (1) perfect chemical equilibrium (detailed balance)

  (2) individual hadronic particles → ideal gas



$T = 160$ MeV

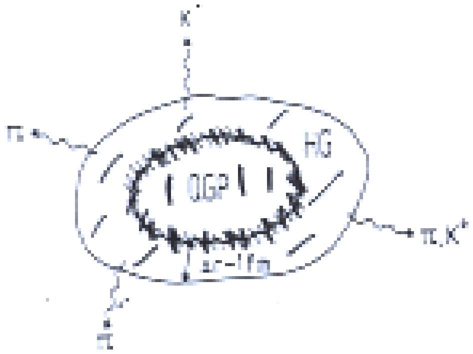
$\mu_B = 170$ MeV

- T=200 MeV ⇒ too many antibaryons . . .:

  T=130 MeV ⇒ too few antibaryons . . .

Particle ratios of a QGP state

- coexistence model *(Greiner, Stöcker)*
  PRD 44, 3517 (1991)

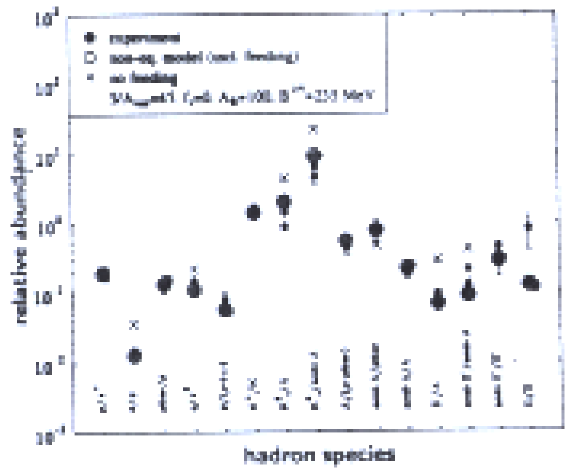


phase coexistence:

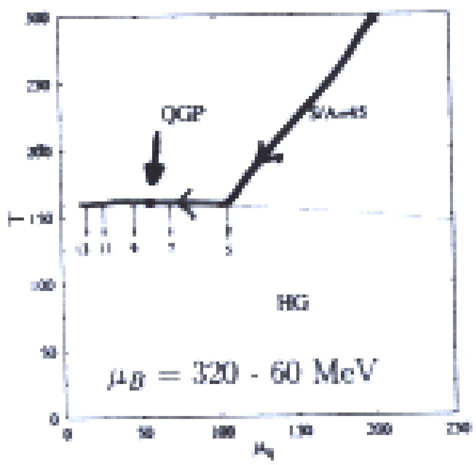
$$T^{QGP} = T^{HG}$$
$$P^{QGP} = P^{HG}$$
$$\mu_B^{QGP} = \mu_B^{HG}$$

- rapid disintegration $\Rightarrow$ particle emission of QGP
  (Spieles, Greiner, Stöcker)
  Eur. Phys. J. C2, 351 (1998)

$B^{\frac{1}{4}} = 235\,\mathrm{MeV}$, $S/A = 45$



B = 400 MeV/fm³



- Analysis demands precise knowledge of particle multiplicities!
- therm. state at (chemical) freeze-out?
  $\leftrightarrow$ Why does it work so good?
- existence of QGP ... ?

- strangeness equilibration in a <u>hadronic gas</u> ...

$\rightarrow$ huge (mass-)thresholds of strange particles

$$p + p \rightarrow p + \underline{\Lambda} + \underline{K} \qquad \Delta m = 670\,\mathrm{MeV}\,;$$

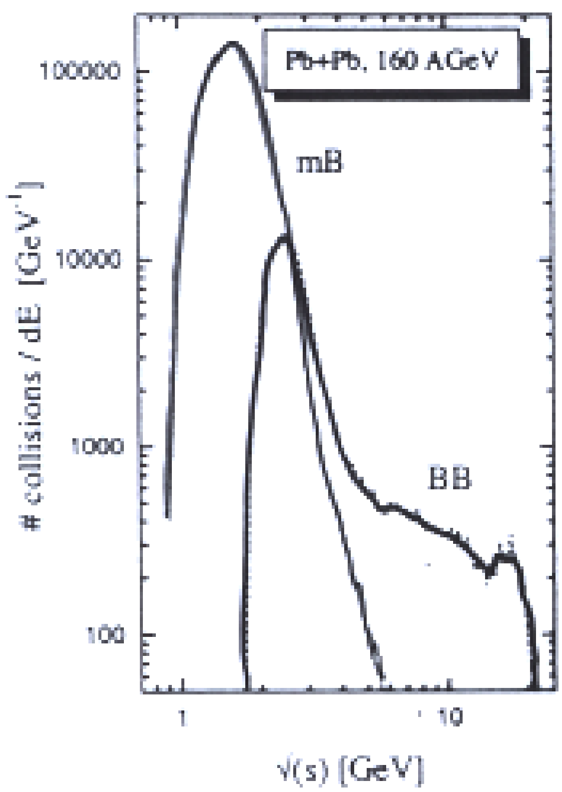
$$p + \pi \rightarrow \underline{\Lambda} + \underline{K} \qquad \Delta m = 535\,\mathrm{MeV}\,;$$

$$\pi + \pi \rightarrow \underline{K} + \underline{\bar{K}} \qquad \Delta m = 720\,\mathrm{MeV}$$

$\rightarrow$ highly suppressed at thermal equilibrium

($\tau_{sat} \sim$100 fm/c)

- **But**: preequilibrium production and resonance decays!



Geiss, Cassing, C.G.
NPA 644, 107 (1998)

Production of Antihyperons: QGP signature ...?

☐ binary strangeness production reaction:

$$\pi + \bar{p} \to K + \Lambda, \Sigma$$
$$(q\bar{q}) \quad (\bar{q}\bar{q}\bar{q}) \quad (s\bar{q}) \quad (\bar{s}\bar{q}\bar{q})$$

$$\pi + \Lambda \to K + \Xi$$
$$(\bar{s}\bar{q}\bar{q}) \quad (\bar{s}\bar{s}\bar{q})$$

$\Delta Q \approx 600$ MeV

$\downarrow$

$\langle\langle \sigma \rangle\rangle \approx 0.01-0.1$ mb

☐ binary strangeness exchange reaction:

$$K + \bar{p} \to \pi + \bar{\Lambda}, \Sigma$$
$$(\bar{s}q) \quad (\bar{s}\bar{q}\bar{q})$$

$$K + \bar{\Lambda} \to \pi + \Xi$$

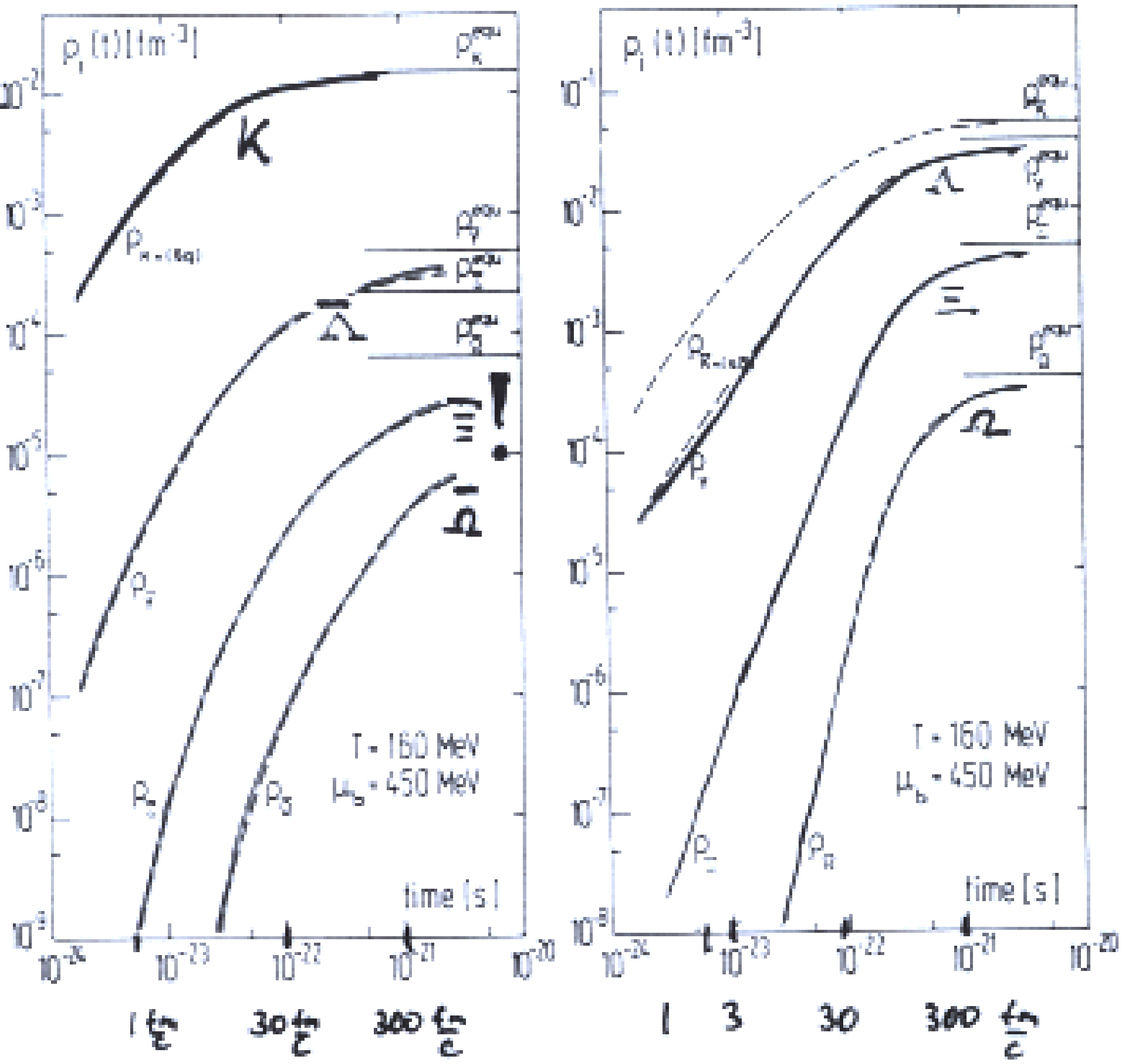
$\langle\langle \sigma \rangle\rangle \lesssim 1$ mb

P. Koch, B. Müller, J. Rafelski, Phys. Rept 142 (19

☐ the **agenda**:

T = 160 MeV

$\boxed{\tau^{chem}_{\bar{Y}} \gtrsim 1000 \frac{fm}{c}}$

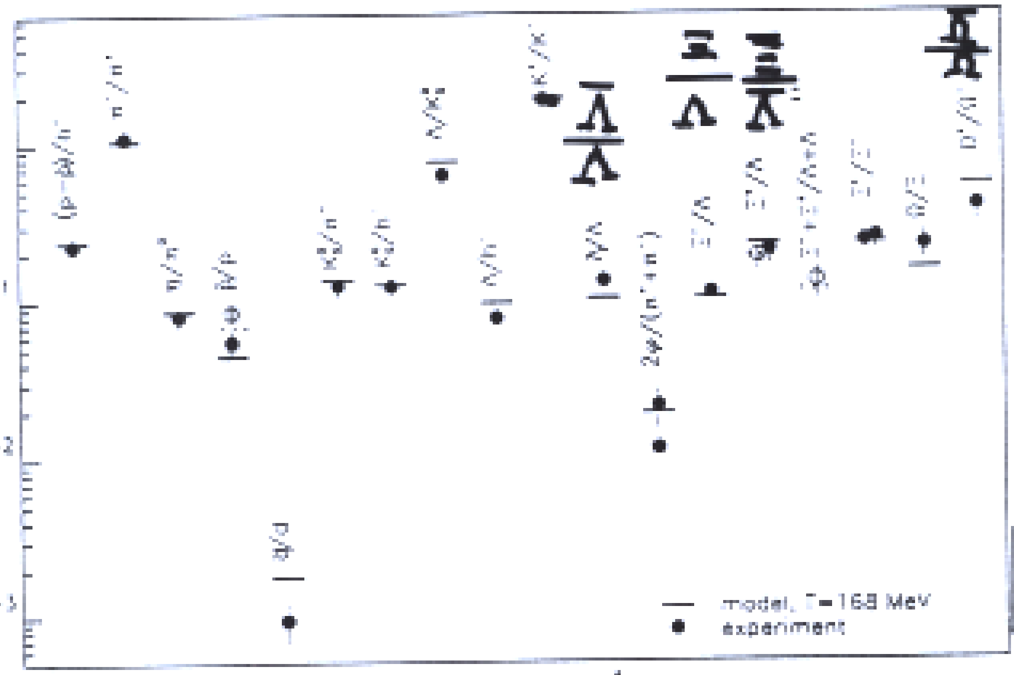


(strange) thermal model analyses:

Pb+Pb

☐ particle ratios:

Braun-Munzinger, Heppe, Stachel
PLB 465, 1 (1999)



$\longleftarrow$ strange $\longrightarrow$

T= 168 MeV

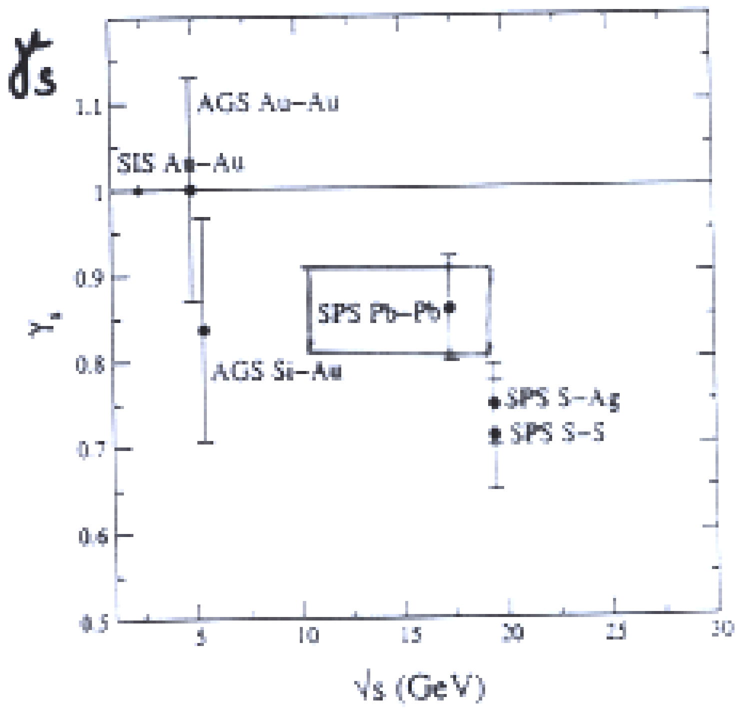
$\boxed{\rho_B \approx 0.5\text{–}0.75\,\rho_0}$

☐ particle yields and 'strangeness' suppression factor:

Becattini et al, hep-ph/0002267

	Calculated	Measured
h^-	157.1	178±22
K^0_S	18.87	21.9±2.4
Λ	14.81	13.7±0.9
$\bar{\Lambda}$	2.254	1.8±0.2
Ξ^-	1.275	1.5±0.1
$\bar{\Xi}^+$	0.4168	0.37±0.06
$\Omega+\bar{\Omega}$	0.2654	0.41±0.08

good agreement



$$N^{eq.} \longrightarrow (\gamma_s)^{\#_s} N^{eq.}$$

Production of Antihyperons: **Multimesonic channels!**

C.G., S. Leupold; nucl-th/0003036

□ $\bar{p}$-production : (Rapp, Shuryak) $\qquad \bar{p} + N \leftrightarrow \overline{n}\pi$ ($\overline{n} \approx 5-7$)

$\sigma_{\bar{p}p} \gtrsim 50\,\mathrm{mb} \xrightarrow{\text{"}\rho_B \approx 0.15\rho_0\text{"}} \qquad (\Gamma_{\bar{p}})^{-1} = \tau_{\bar{p}} \approx 3\,\mathrm{fm/c}$

$\left(\mu_{\bar{p}} \approx -\mu_B + \langle n \rangle \mu_\pi \right)$

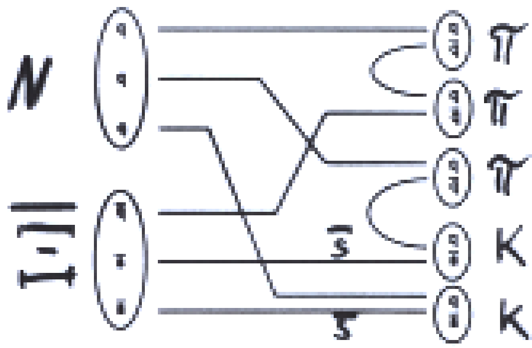
$T_{\mathrm{decoupling}} \approx 120\,\mathrm{MeV}$

■ $\bar{Y}$-production :

$$\underset{(\bar{s}\bar{q}\bar{q})}{\bar{\Lambda}} + N \leftrightarrow n_{\bar{\Lambda}}\pi + K$$

$$\underset{(\bar{s}\bar{s}\bar{q})}{\bar{\Xi}} + N \leftrightarrow n_{\bar{\Xi}}\pi + 2K$$

$$\underset{(\bar{s}\bar{s}\bar{s})}{\bar{\Omega}} + N \leftrightarrow n_{\bar{\Omega}}\pi + 3K$$



$$\boxed{\bar{Y} + N \leftrightarrow n\pi + n_Y K} \qquad n + n_Y \approx 5-7$$

□ Two basic **assumptions:**

$$\boxed{(\mathrm{I})\ \sigma_{N\bar{Y}} \approx \sigma_{N\bar{p}}}$$

before chem. freeze out

$$\boxed{(\mathrm{II})\ \rho_\pi \approx \rho_\pi^{eq.} \quad , \quad \rho_N \approx \rho_N^{eq.}} \boxed{, \quad \rho_K \approx \rho_K^{eq.}}$$

□ ⇒ chemical equilibration time:

annihilation rate

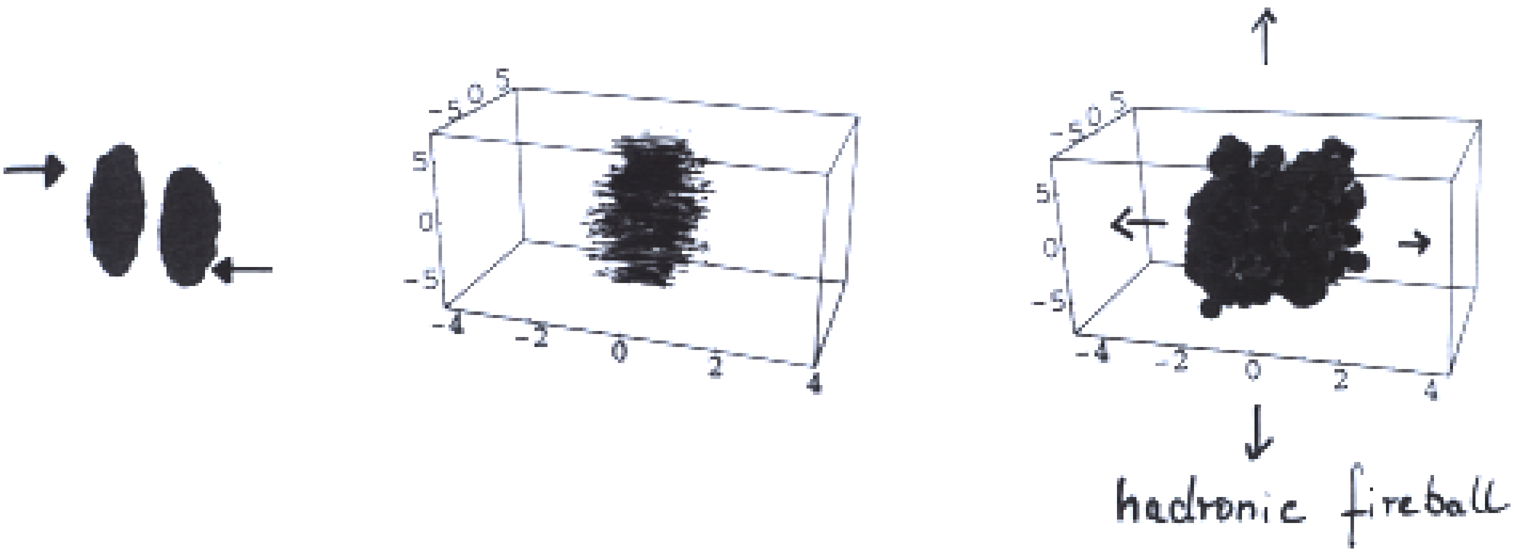
$\rho_B \approx 1-2\,\rho_0$

$$(\Gamma_{\bar{Y}})^{-1} = \tau_{\bar{Y}} := \frac{1}{\langle\langle \sigma_{N\bar{Y}\to n\pi + n_Y K} v_{\bar{Y}N} \rangle\rangle \rho_B} \approx \underline{1 - 3\,\mathrm{fm/c}}$$

Initial baryon density $\rho_B(t_i)$ ...

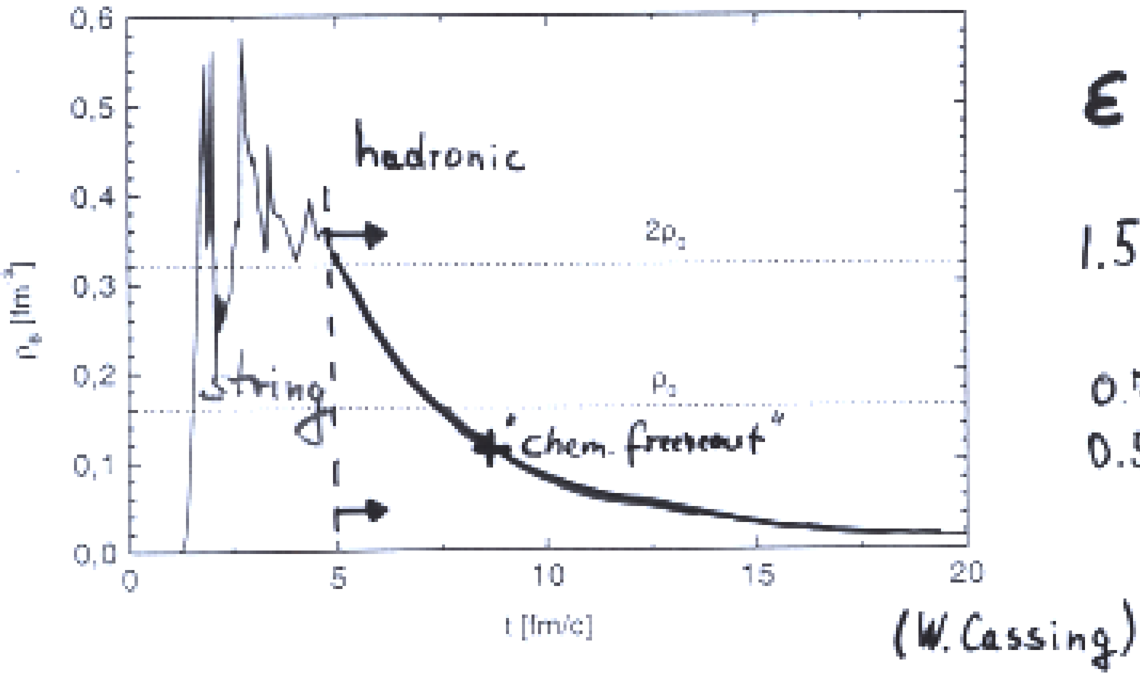
□ prehadronic string excitations:

HSD



baryon density

$|\Delta Y| \leq 1$



$\varepsilon \approx$

$1.5 \ \frac{GeV}{fm^3}$

$0.7 \ \frac{GeV}{fm^3}$

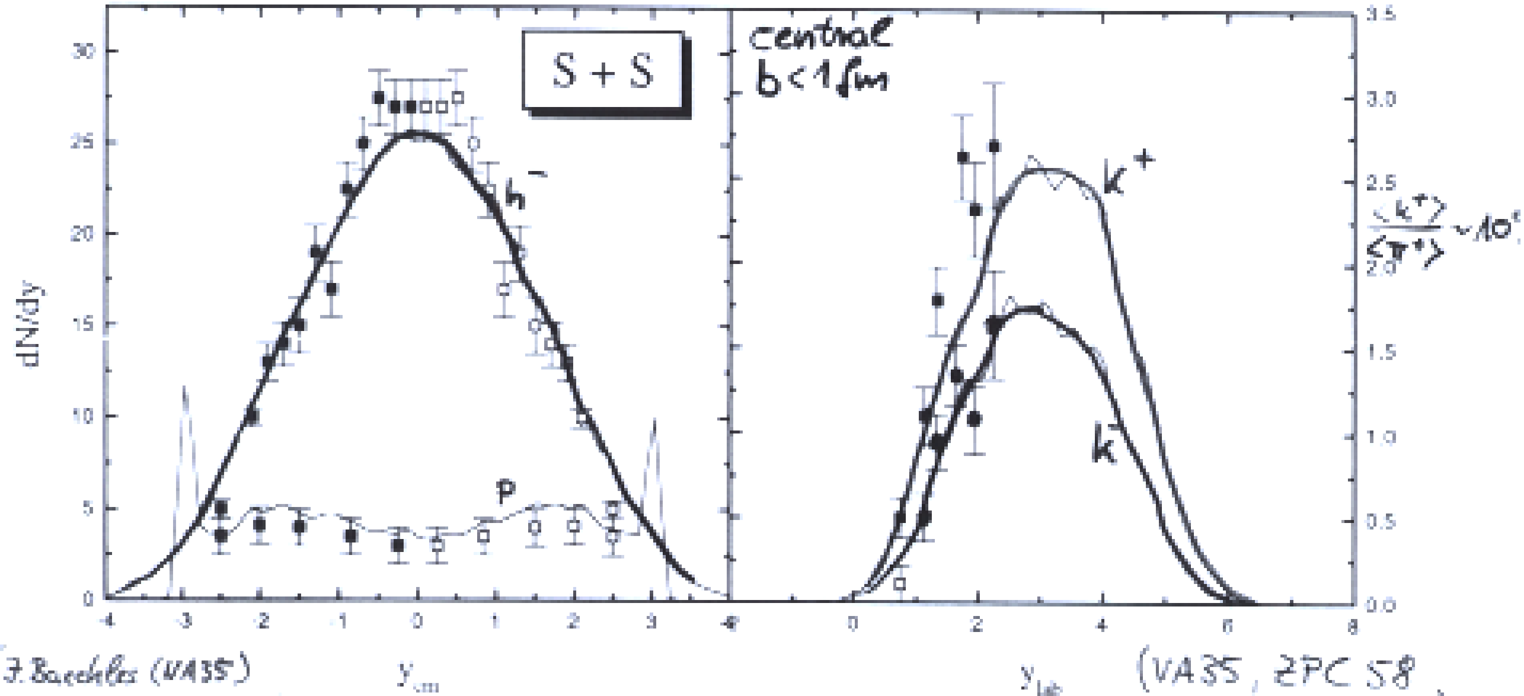
0.5 "

$\underset{\sim}{\epsilon} \approx \langle E_B \rangle \rho_B + \langle E_\pi \rangle 6 \rho_B \approx \underline{4.3\, \rho_B\, GeV/fm^3}$

Weiss, Cassing, C.G.
NPA 644, 107 (1998)

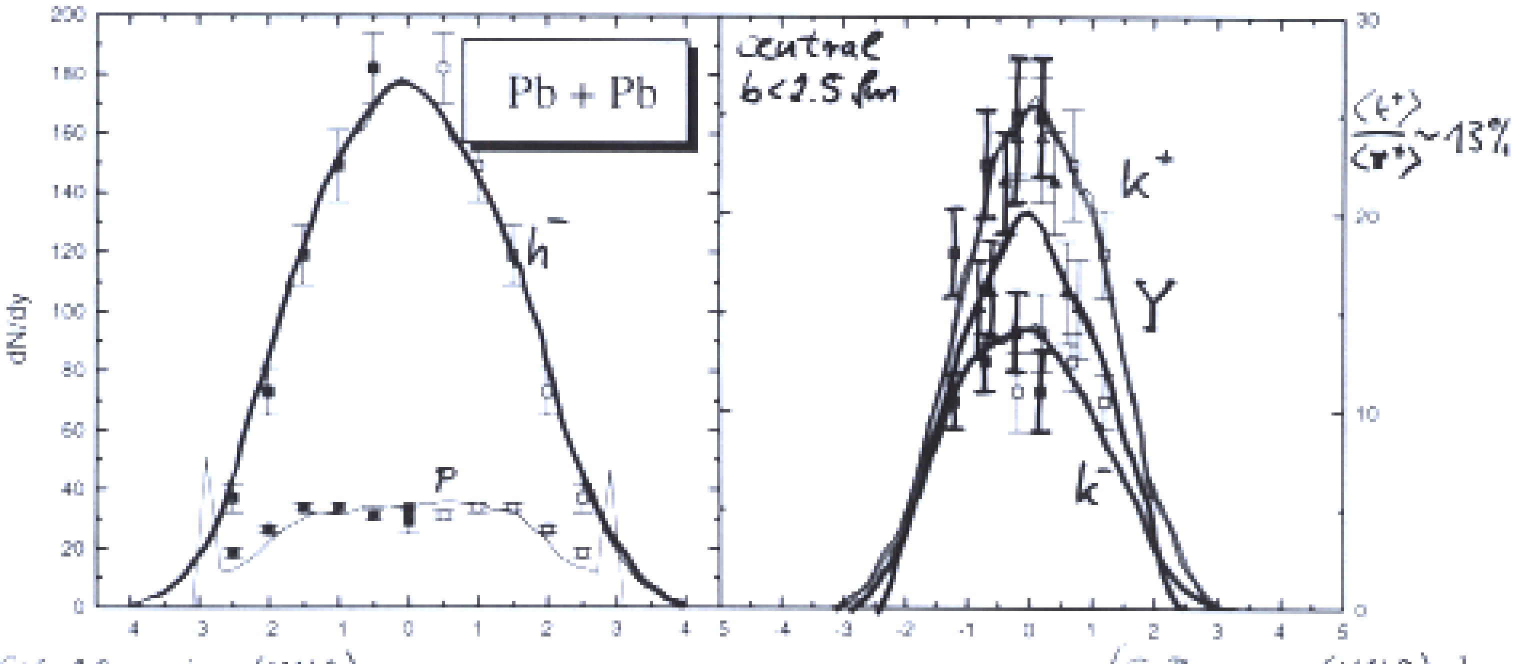
Strangeness production at SPS energies:

neg. hadrons and protons   charged kaons



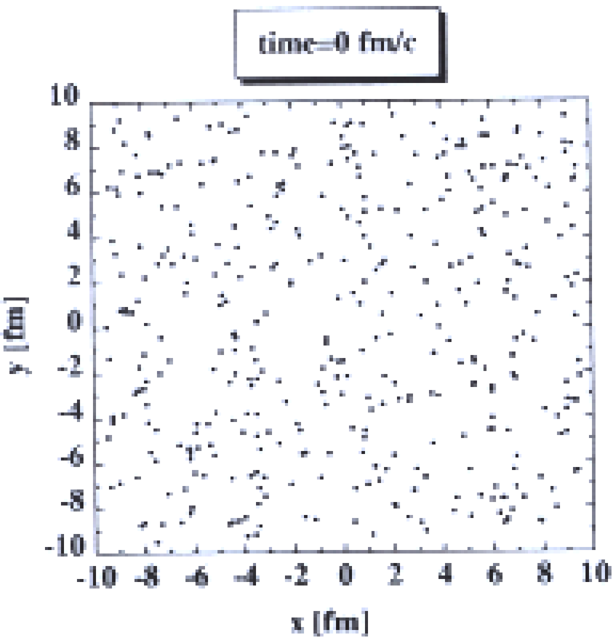
(J. Baechler (NA35) PRL 72 (1994) 1419)   (NA35, ZPC 58 (1993) 367)

neg. hadrons and protons   charged kaons, hyperons

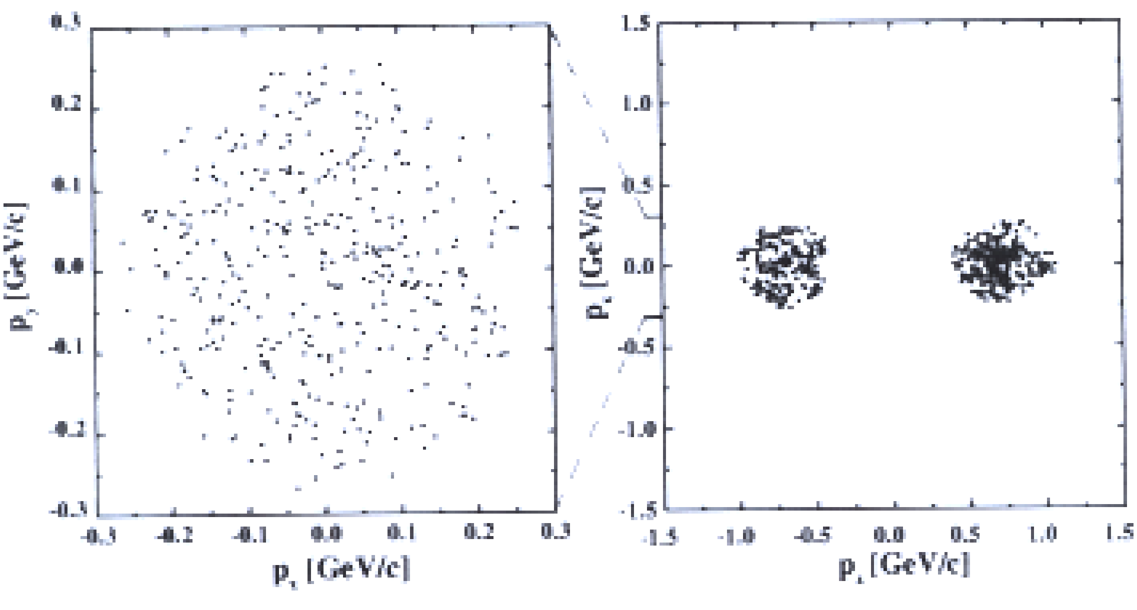


(S.V. Afanasiev (NA49) NPA 610 (1996) 188c)   (C. Bormann (NA49) Jour. of Phys. G 23 (1997) 1817)

Distribution in coordinate space

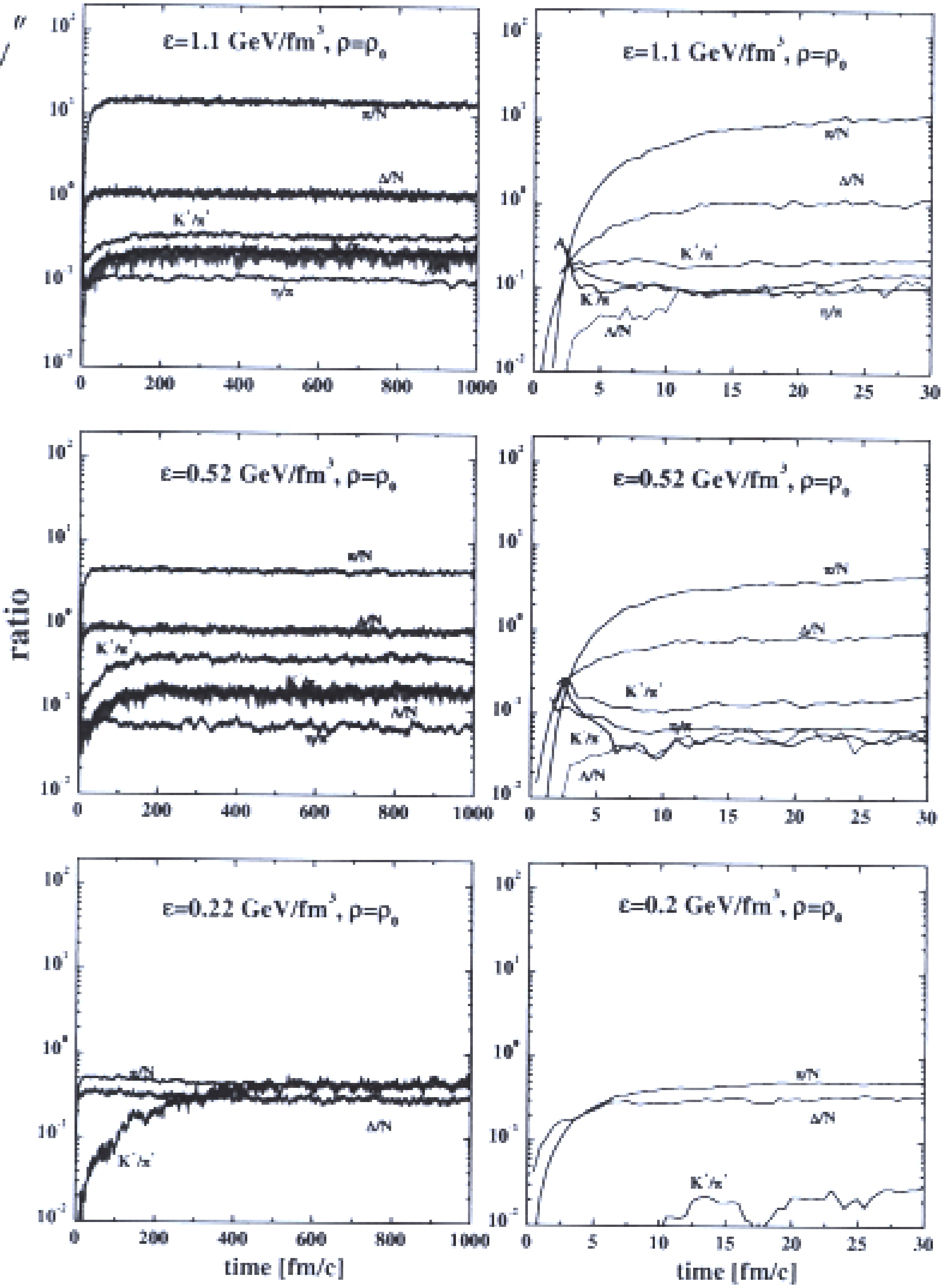


Distribution in momentum space



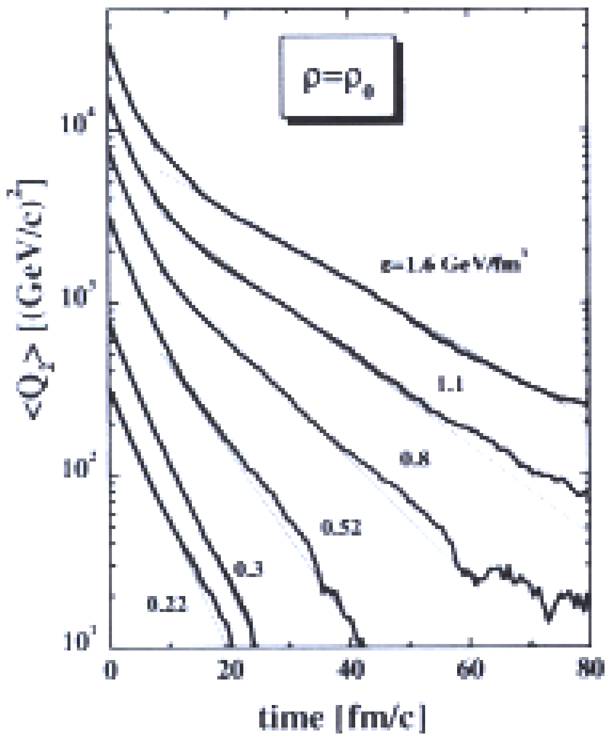
E. Bratkovskaya et al,
NPA 674,249(200

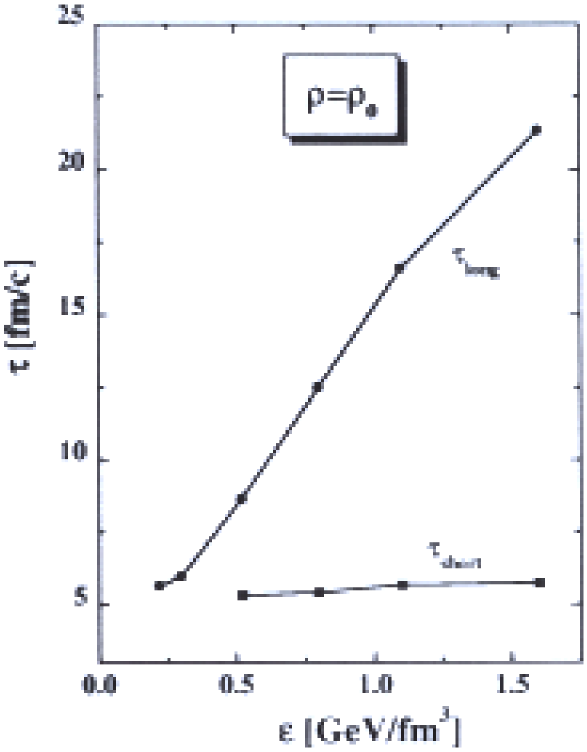
'CERN'
SPS



→ in HIC <u>bulk</u> of strange particles produced at beginning

Time evolution of the quadrupole moment $<Q_2> = < 2p_z^2 - p_x^2 - p_y^2 >$ for density $\rho = \rho_0$ at different energy densities ε





Exponential fit:

$$< Q_2 > (t) \simeq A_1 \exp(-t/\tau_{short}) + A_2 \exp(-t/\tau_{long})$$

$\tau_{short} \Longrightarrow$ string decays

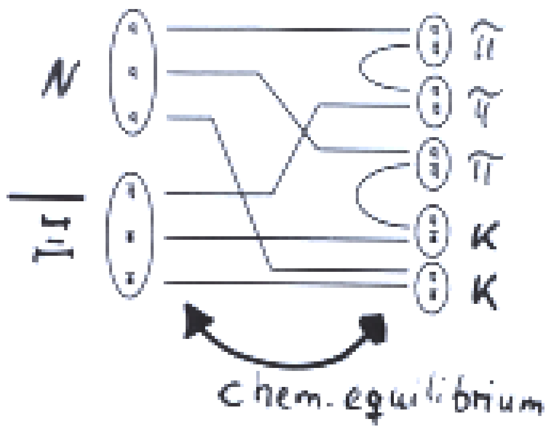
$\tau_{long} \Longrightarrow$ hadron interactions

(forward peaked)

$$\tau_{short} \sim \frac{1}{\frac{\rho}{2} \langle \sigma_{MM} v_{MM} \rangle} + \tau_{formation}$$

☐ Kinetic Master equation:

(thermal models)



$$\frac{d}{dt}\underline{\rho_{\bar{Y}}} = -\underline{\langle\langle \sigma_{\bar{Y}N} v_{\bar{Y}N} \rangle\rangle} \left\{ \underline{\rho_{\bar{Y}}}\rho_N - \sum_n p_n \underline{\mathcal{R}_{(n,n_Y)}} (\rho_\pi)^n (\rho_K)^{n_Y} \right\}$$

with $\underline{\mathcal{R}_{(n,n_Y)}}(T,\mu_B,\mu_s) = \dfrac{\rho_{\bar{Y}}^{eq.}\rho_N^{eq.}}{(\rho_\pi^{eq.})^n(\rho_K^{eq.})^{n_Y}}$ – detailed balance

(mass law action)

☐ More **intuitive** form:

$\langle\langle \sigma_N v \rangle\rangle \rho_B$

$$\frac{d}{dt}\rho_{\bar{Y}} = -\Gamma_Y \rho_{\bar{Y}} + \mathcal{G}_{\bar{Y}} \longrightarrow$$

$$\boxed{= -\Gamma_{\bar{Y}} \left\{ \rho_{\bar{Y}} - \rho_{\bar{Y}}^{eq} \right\}}$$

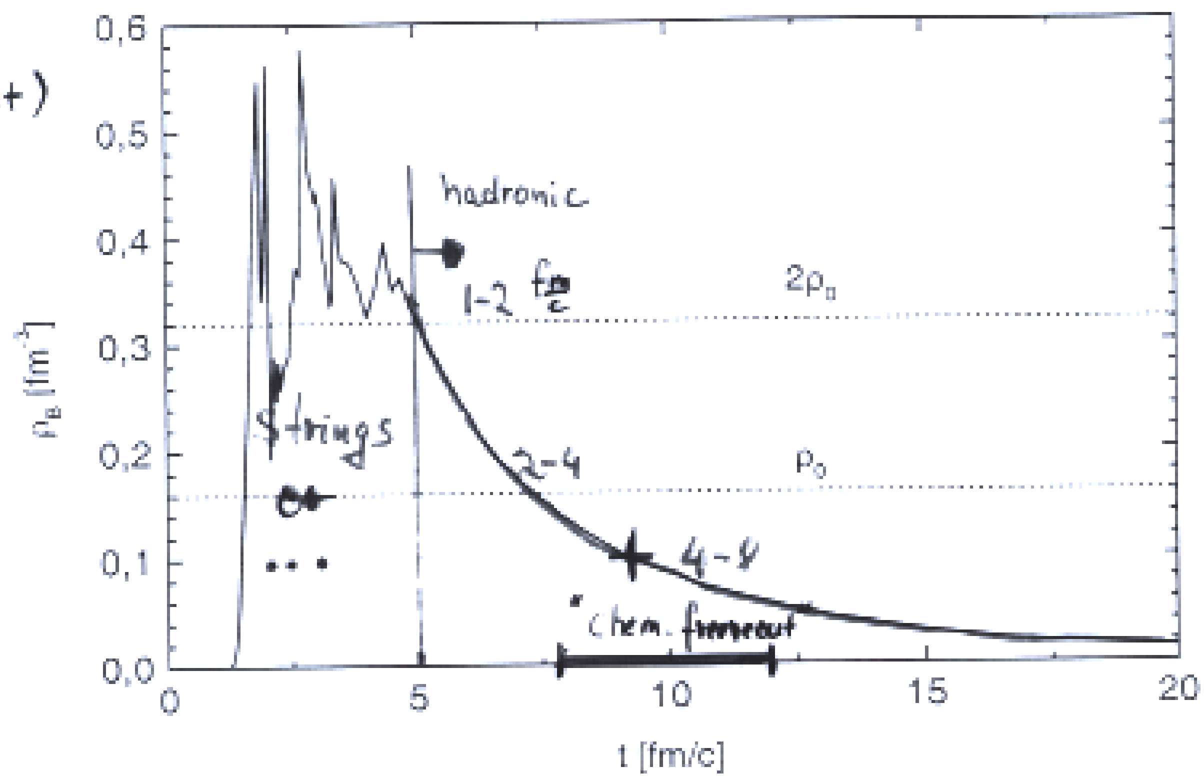
☐ not fully equilibrated strangeness:

$$\rho_K^{eq.} \to \rho_K = \underline{\gamma_s \rho_K^{eq.}} \Longrightarrow$$

$$\rho_{\bar{Y}}^{eq} \to \rho_{\bar{Y}} = \underline{(\gamma_s)^{n_Y}} \rho_{\bar{Y}}^{eq.}$$

Fast expansion scale $V(t)$ ...

$\rho_B(+)$



$(\tau_{eq})^{-1} \sim$

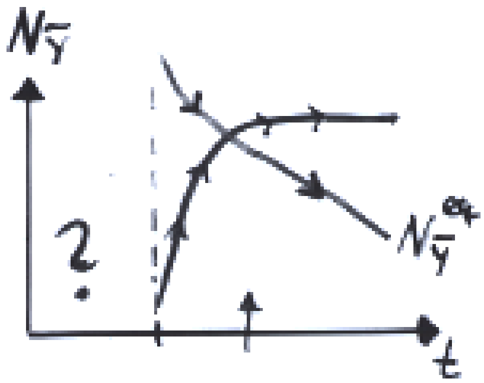
$\underline{\underline{\Gamma_{\bar{Y}}(t)}} \sim$

$\rho_B(t) \sim$

$1/V(t)$

$$\frac{d}{dt} N_{\bar{Y}} = -\underline{\Gamma_{\bar{Y}}(t)} \left\{ N_{\bar{Y}} - \underline{N_{\bar{Y}}^{eq.}} \sum_n p_n \left(\frac{N_\pi}{N_\pi^{eq.}}\right)^n \left(\frac{N_K}{N_K^{eq.}}\right)^{n_Y} \right\}$$

□ $$\frac{N_{\bar{Y}}^{eq.}}{N_B}(T) \sim e^{-(m_Y + 2\mu_B - m_N - \mu_s)/T}$$



$\hookrightarrow$ might, after all, explain the location of

chemical freezeout.

Multistrange hyperons ...

☐ **Y-production** : $Y + \bar{N} \leftrightarrow n\pi + n_Y \bar{K}$ (?)

production rates:

$$\underline{\Gamma_{Y}^{eff}} = \langle\langle \sigma_{N\bar{Y}} v \rangle\rangle \underline{\rho_B \rho_{\bar{Y}}^{eq.}} \quad \longleftrightarrow \quad \underline{\Gamma_{\bar{Y}}^{eff}} = \langle\langle \sigma_{Y\bar{N}} v \rangle\rangle \underline{\rho_{\bar{B}} \rho_{Y}^{eq.}}$$

One has $\frac{\rho_B \rho_{\bar{Y}}^{eq.}}{\rho_{\bar{B}} \rho_{Y}^{eq.}} \approx e^{2\mu_s/T} \equiv \underline{\left(\frac{\rho_K}{\rho_{\bar{K}}}\right)^2} > 1$ and $\overset{\text{SPS}}{\underline{\rho_{Y}^{eq.} \gg \rho_{\bar{Y}}^{eq.}}}$

$\hookrightarrow$ Ys would need much longer for chem. equilibration

☐ recent conjecture: fundamental importance of rescattering

$$\boxed{\Lambda + \pi \leftrightarrow \Xi + K \quad , \quad \Xi + \pi \leftrightarrow \Omega + K}$$

(S. Vance, nucl-th/0012056;

N. Amelin et al. hep-ph/0012276)

Summary

- To prove for QGP, one has to test for (more) conventional alternatives (!)
- Antihyperons are produced by multi-mesonic processes
  - on a very short timescale (!)
  - $\bar{Y}$ are *no* QGP signature, but ...
  - clear indication for dense hadronic and eq. system
  - relevance of multi-particle interactions
  - $\bar{Y}$-physics cannot be adressed by today transport algorithms (!)
- Should be true at AGS (!):

$$\boxed{\frac{\bar{\Lambda}}{\bar{p}} \approx 3}$$

E 859
E 864

$$\frac{N_{\bar{\Lambda}}}{N_{\bar{p}}} \approx \left(\frac{m_\Lambda}{m_p}\right)^{\frac{3}{2}} e^{-(m_\Lambda - m_p - \mu_s)/T} \approx 1$$

$\bar{\Sigma}^0$
≈ 1.6

- Should be lesser true at RHIC