IN-MEDIUM EFFECTS ON THE K^-/K^+ RATIO AT GSI

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Outline of Talk

1. **K^-/K^+ ratio: medium effects?**

2. Thermal models: K^+/K^- ratio

3. **In-medium properties of K^-**

4. **Results for K^+/K^- ratio at GSI**

5. **Conclusions**

K^-/K^+ ratio: medium effects?

HEAVY-ION COLLISIONS at GSI (1-2 AGeV):

K^- in hot and dense matter[a]

- K^-/K^+ ratio: enhancement at energies below threshold (pp⇔nucleus-nucleus)

$$NN \to K^+ \Lambda N \quad 1.58 GeV$$

$$NN \to K^+ K^- NN \quad 2.5 GeV$$

- $K^-/K^+ \sim ct$ for C+C , Ni+Ni , Au+Au

  Absorption K^- via $K^- N \to Y\pi$ suppressed

  and/or enhanced K^- production

- Centrality independence of K^-/K^+ ratio
  - $K^+$and K^- yields strongly correlated [b]
  - Thermal models: free particles and volume cancels out exactly. [c]
  - "Broad-band equilibration" by Brown et al.[d]

[a] *Oeschler, JPG 28, 1787 (2002); Senger, NPA 685, 312 (2001); Sturm et al., JPG 28, 1895 (2002)*

[b] *Hartnack et al., PRL 90, 102302 (2003)*

[c] *Cleymans et al., PRC 60, 054908 (1999)*

[d] *Brown et al., NPA 690, 184c (2001); NPA 698, 483c (2002)*

Thermal models: K^+/K^- ratio

Hadronic Gas Model (μ_B, T) [a]

using CANONICAL scheme for **STRANGENESS**

K^+/K^- independent of VOLUME

$\Downarrow$

independent CANONICAL OR
GRAND-CANONICAL treatment

$$\frac{K^+}{K^-} = \frac{Z^1_{K^+}}{Z^1_{K^-}} \; \frac{Z^1_{K^-} + Z^1_{B,S=-1} + Z^1_{M,S=-1}}{Z^1_{K^+} + Z^1_{M,S=+1}}$$

$K^+/K^- \sim 33$ at 1.93 AGeV in Ni+Ni [b]

Data described: [c]

$$T = 70 \pm 10 MeV,\ \mu_B = 720 \pm 30 MeV$$

[a] *Cleymans et al., PLB 485, 27 (2000) and PRC 59 ,1663 (1999)*
[b] *Menzel et al., PLB 495, 26 (2000)*
[c] *Cleymans et al., PRC 57, 3319 (1998)*

In-medium properties of K^-

$$\frac{K^+}{K^-} = 1 + \frac{Z^1_\Lambda + Z^1_\Sigma + Z^1_{\Sigma*}}{Z^1_{K^-}} \sim e^{\frac{\mu_B + "U_{K^-}"}{T}}$$

- Mean-field for Λ and Σ, and Breit-Wigner for Σ^*

$$Z^1_{\Lambda,\Sigma} = g_{\Lambda,\Sigma} V \int \frac{d^3p}{(2\pi)^3} e^{\frac{-\sqrt{m^2_{\Lambda,\Sigma}+p^2} - U_{\Lambda,\Sigma}(\rho)}{T}} e^{\frac{\mu_B}{T}}$$

$$Z^1_{\Sigma*} = g_{\Sigma*} V \int \frac{d^3p}{(2\pi)^3} \int ds\, e^{\frac{-\sqrt{p^2+s}}{T}} \frac{1}{\pi} \frac{m_{\Sigma*}\Gamma}{(s - m^2_{\Sigma*})^2 + m^2_{\Sigma*}\Gamma^2} e^{\frac{\mu_B}{T}},$$

- K^- meson in hot and dense matter
  - ON SHELL

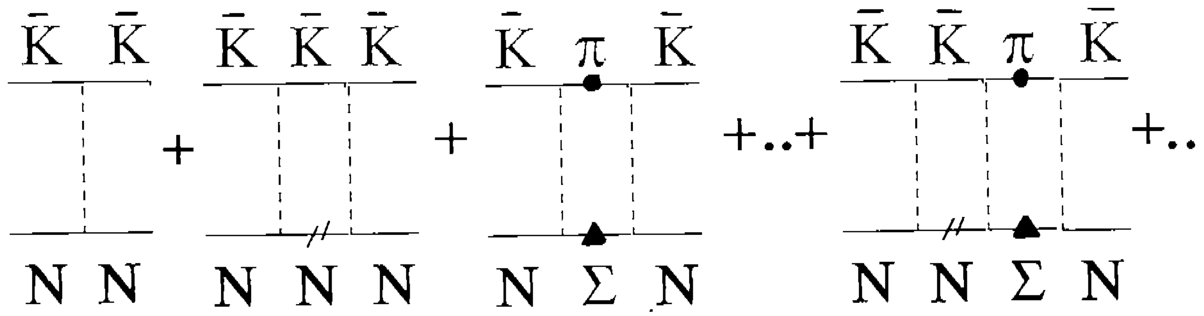
$$Z^1_{K^-} = g_{K^-} V \int \frac{d^3p}{(2\pi)^3} e^{\frac{-E_{K^-}}{T}}$$

$$E_{K^-} = \sqrt{m_{K^-} + p^2} + \mathrm{Re}\, U_{K^-}(p, E_{K^-}, \rho, T),$$

  - SPECTRAL DENSITY

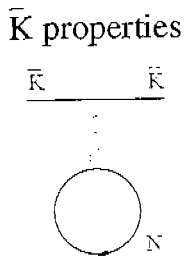
$$Z^1_{K^-} = g_{K^-} V \int \frac{d^3p}{(2\pi)^3} \int ds\, S_{\bar{K}}(p, \sqrt{s}, \rho, T)\, e^{\frac{-\sqrt{s}}{T}}$$

Microscopic calculation of the in-medium $\bar{K}N$ interaction (G-matrix) and the K^- optical potential from $T = 0$ to T finite in nuclear matter.



$$G = V + V\frac{Q}{\omega - H_0}V + V\frac{Q}{\omega - H_0}V\frac{Q}{\omega - H_0}V + \cdots$$

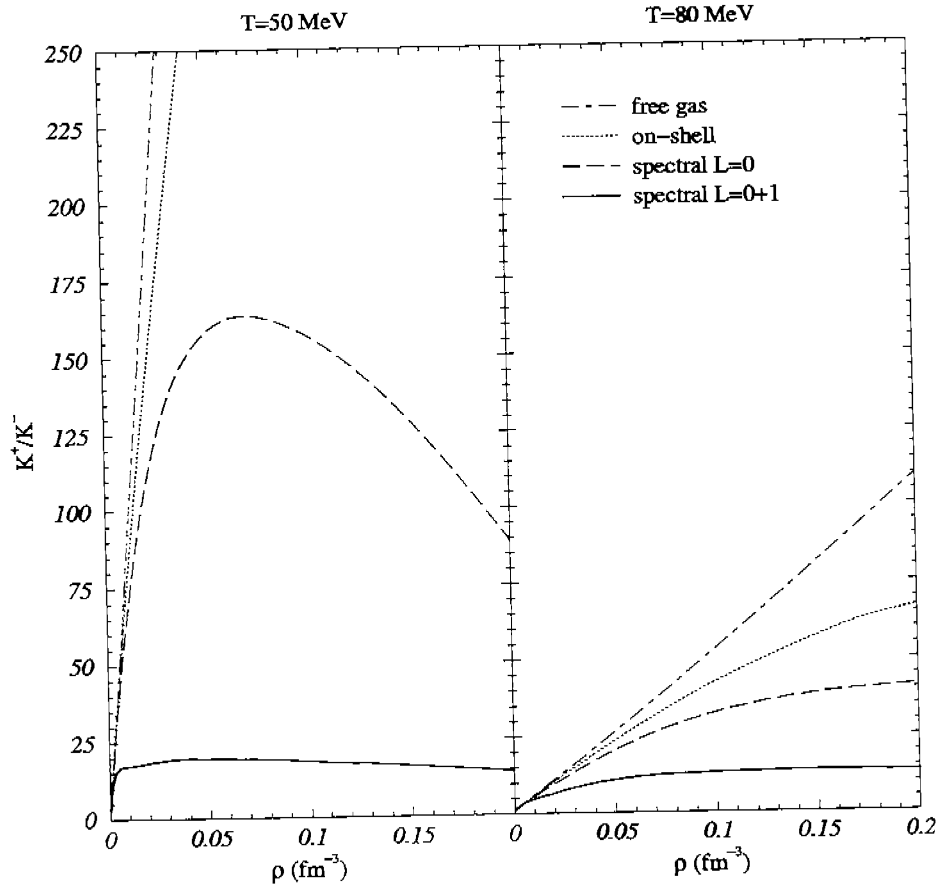
$$G = V + V\frac{Q}{\omega - H_0}G \quad \text{Bethe–Goldstone eq.}$$



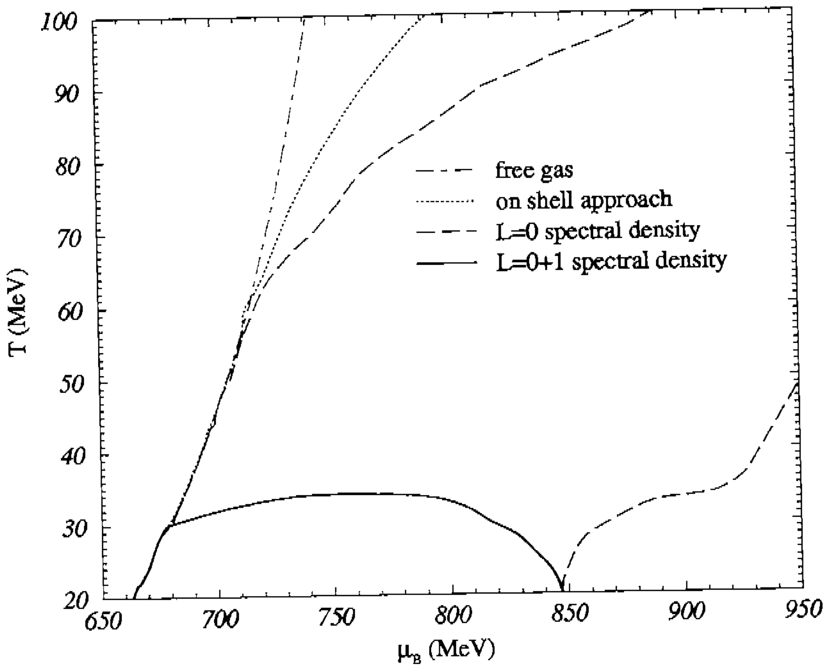
Jülich meson–exchange bare potential V

A. Müller et al., Nucl. Phys. A 513, 557 (1990)

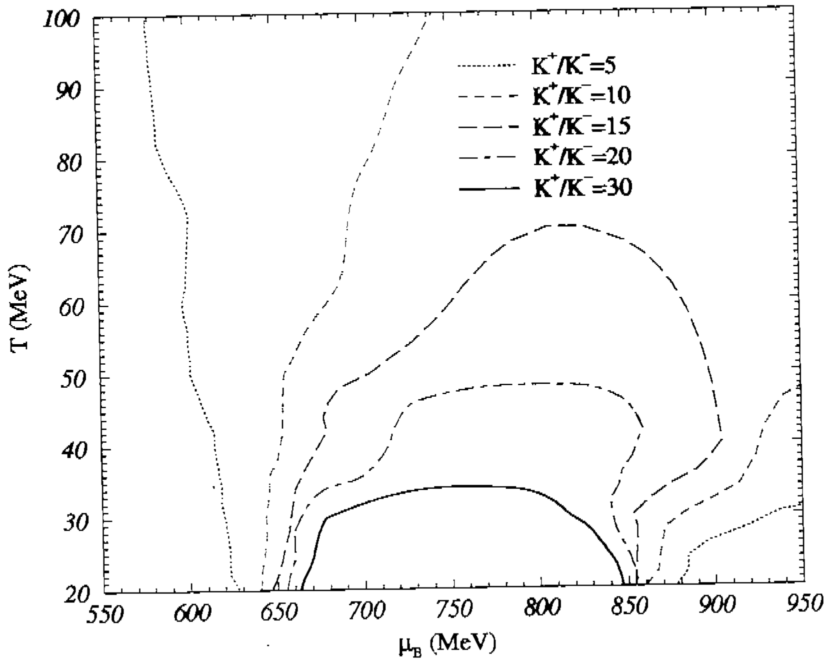
Results for K^+/K^- ratio at GSI



- K^+/K^- ratio grows with $e^{\mu_B/T}$
- **K^- properties in hot and dense matter** make the curves bend down
- Inclusion of K^- spectral density implies additional attraction → qualitative agreement with "Broad-band equilibration"



$T(\mu_B)$ for K^+/K^- =30 within different approaches



Different K^+/K^- ratios using the K^- spectral density

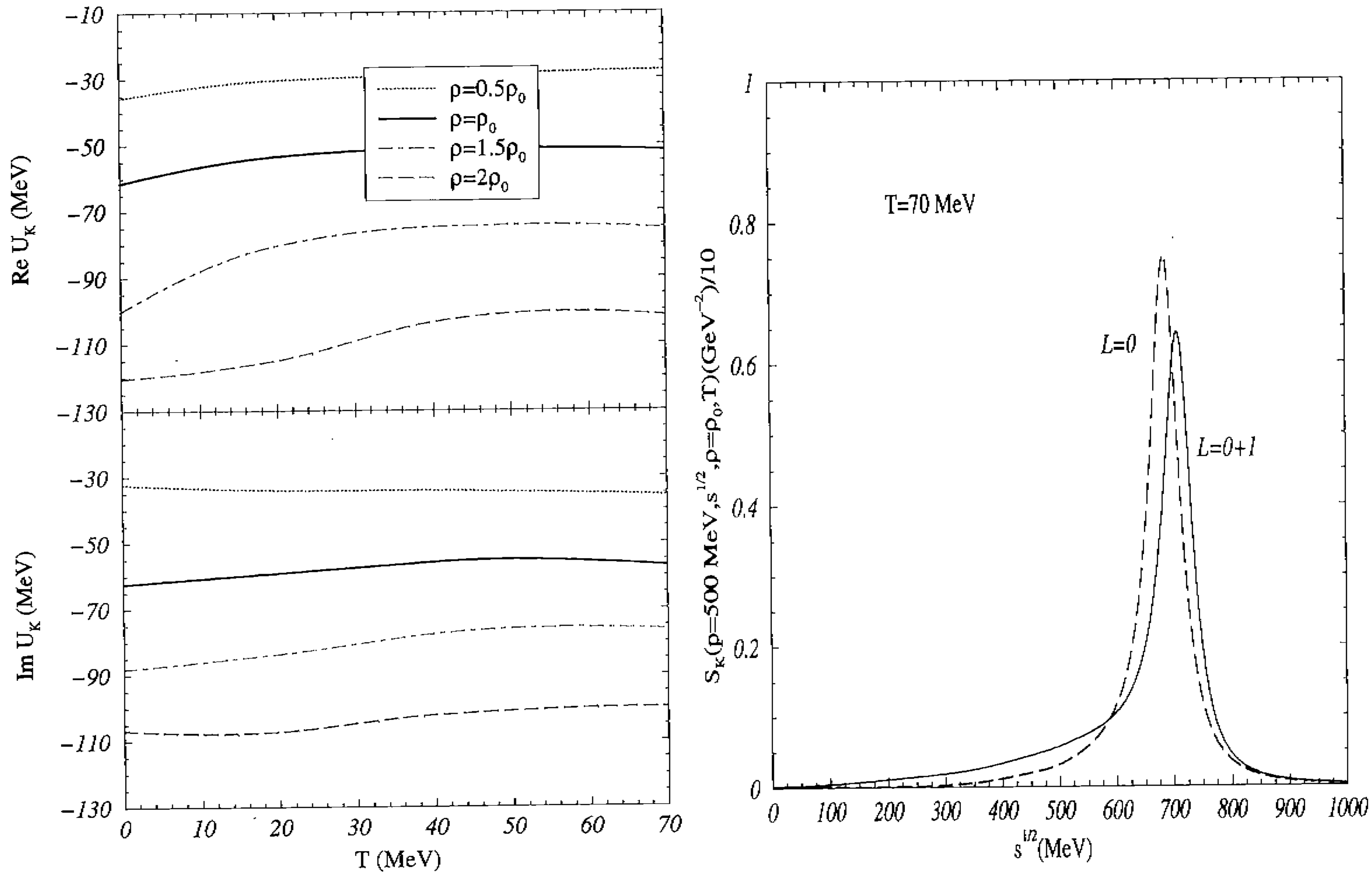
Conclusions

- $T(\mu_B)$ compatible with K^-/K^+ is very delicate depending very strongly on the approach ($T \approx 35$ MeV and $\mu_B \to 850$ MeV for $K^+/K^- \approx 30$ with the K^- spectral density).
- **On-shell approach** does not achieve Brown's "Broad-band equilibration" because of a stronger increase of μ_B with density and a less attractive U_{K^-}.
- "Broad-band equilibration" obtained only when **the K^- spectral density** is used. However, K^- is in excess ⇒ dynamical non-equilibrium effects to explain the smaller number of K^- detected.

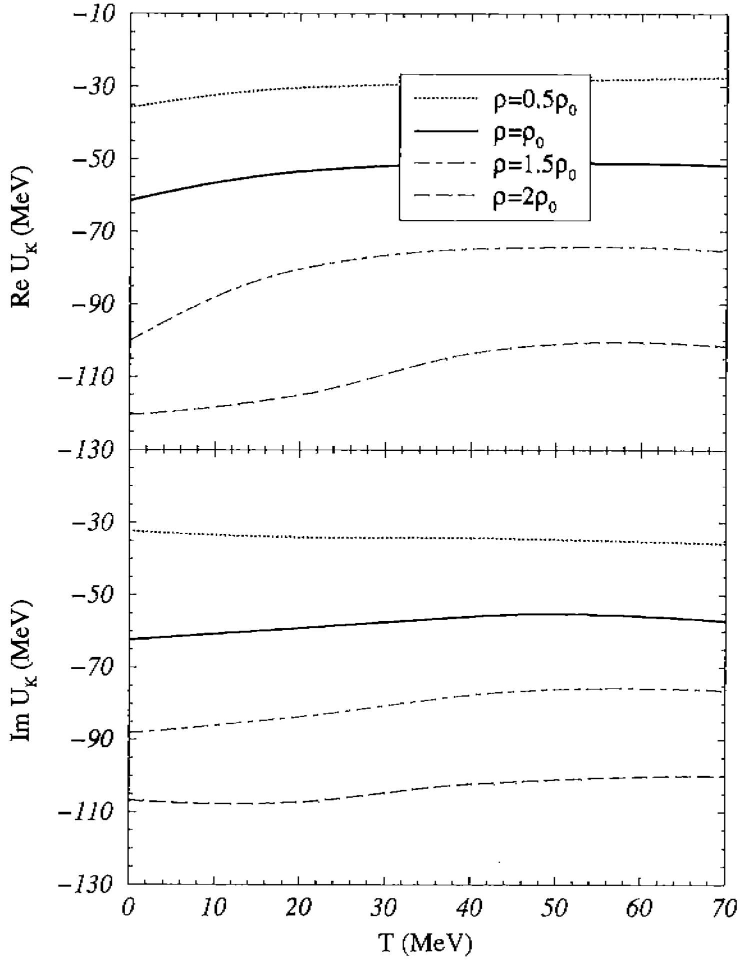
Tolós, Polls, Ramos and Schaffner-Bielich,

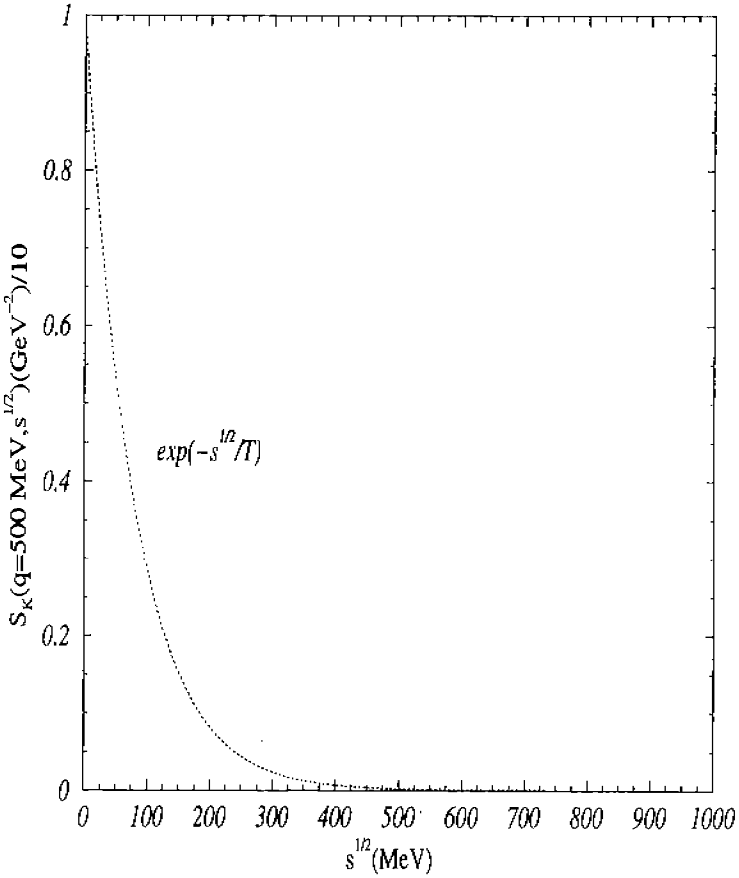
Phys. Rev. C 68, 024903 (2003)

L. Tolós, A. Ramos, and A. Polls, Phys. Rev. C 65, 054907 (2002)



1. On-shell aproximation(left panel): in-medium U_{K^-} at finite temperature.
2. K^- spectral density (right panel) using K^- self-energy.


Re U_K (MeV)
Im U_K (MeV)
T (MeV)
ρ=0.5ρ0
ρ=ρ0
ρ=1.5ρ0
ρ=2ρ0


$S_K(q=500$ MeV$,s^{1/2})$(GeV^{-2})/10
$exp(-s^{1/2}/T)$
$s^{1/2}$(MeV)