Transport and In-Medium Effects

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Outline

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- What type of medium effects?

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- Quasi-particle picture

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- Beyond quasi-particles

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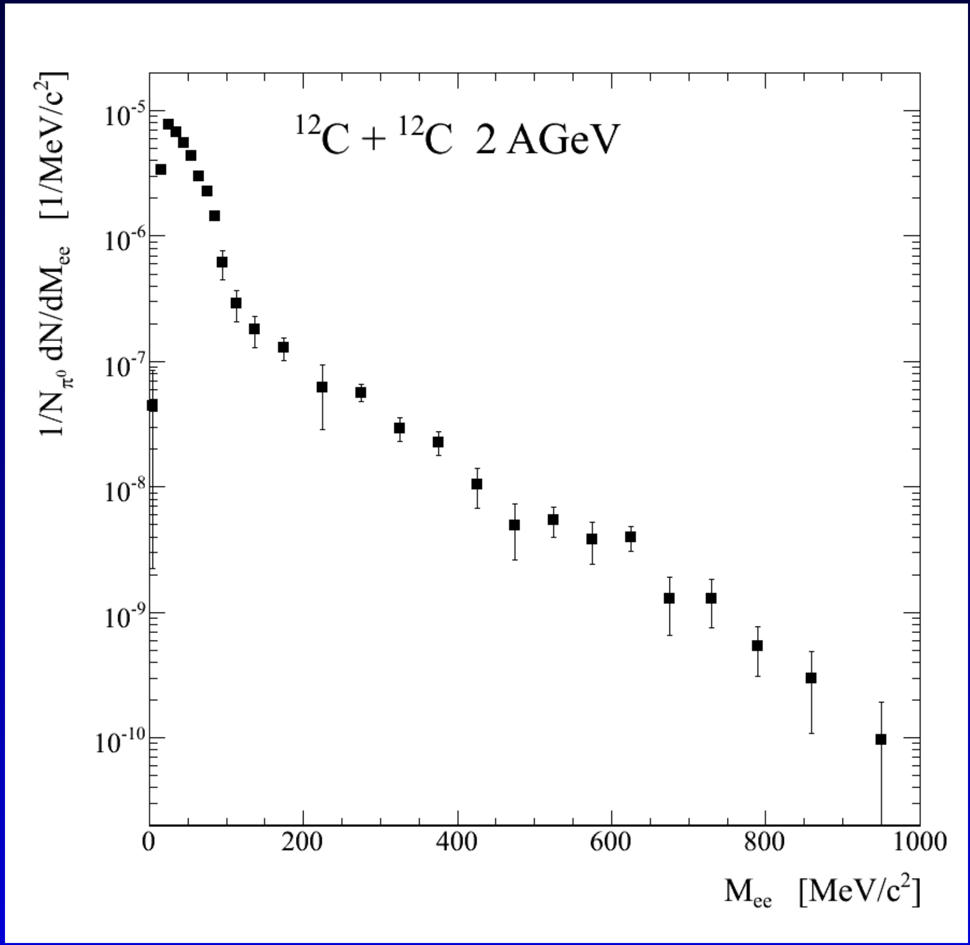
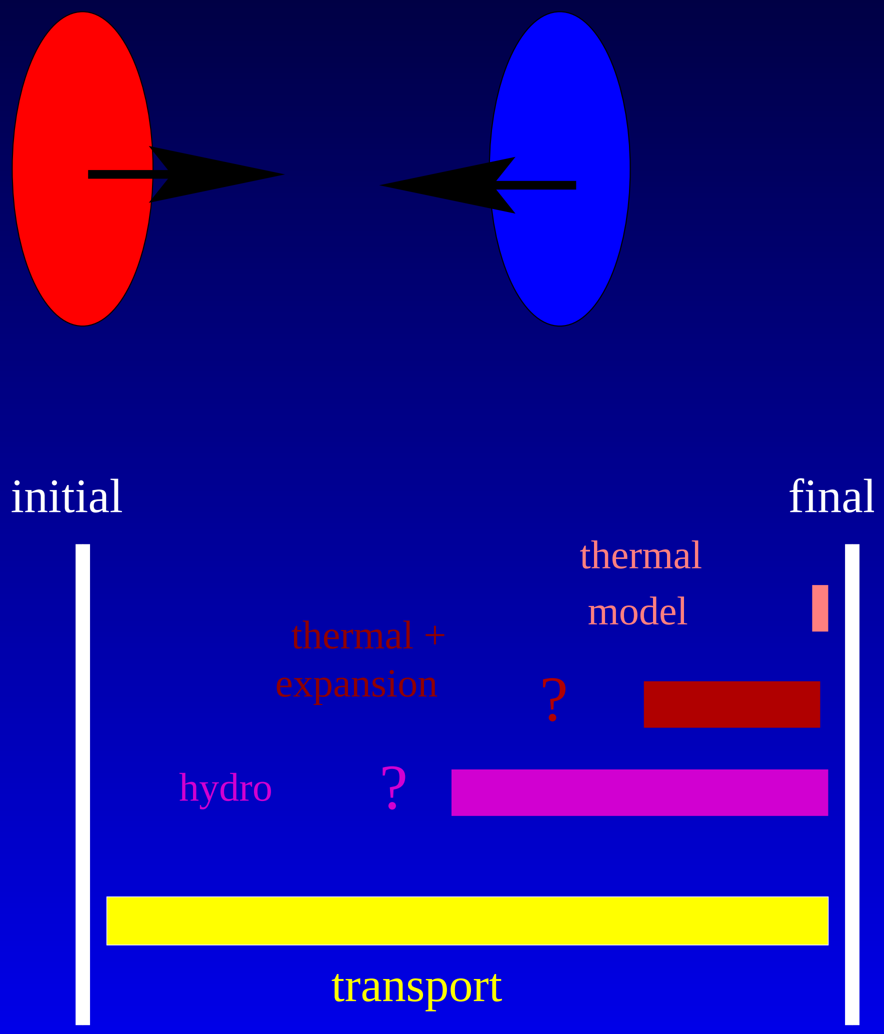
- What type of medium effects?
- Quasi-particle picture
- Beyond quasi-particles
- Open questions

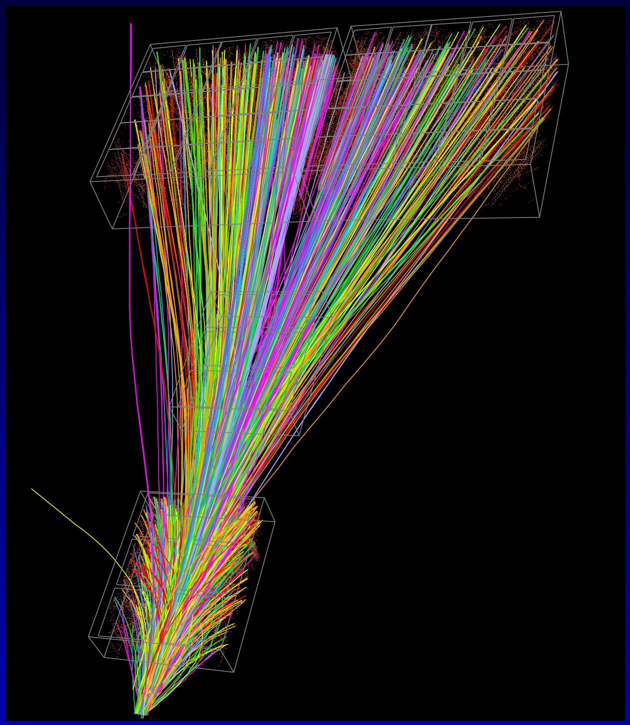
Why do we need transport?

HADES: first e^+e^- data, C+C, inclusive



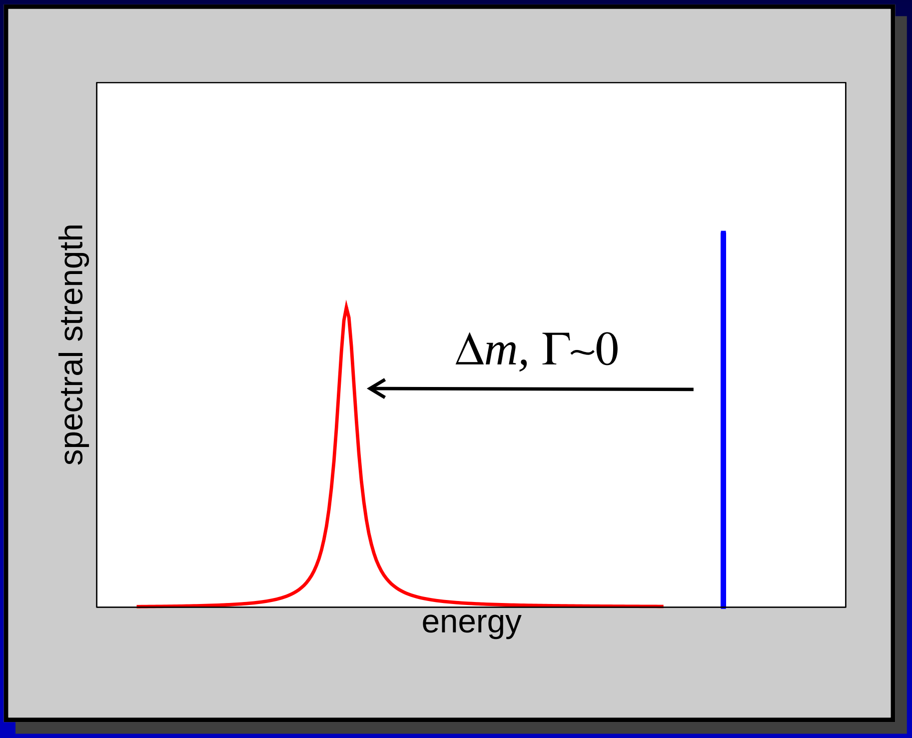
Models for heavy ion collisions





Medium effects & transport

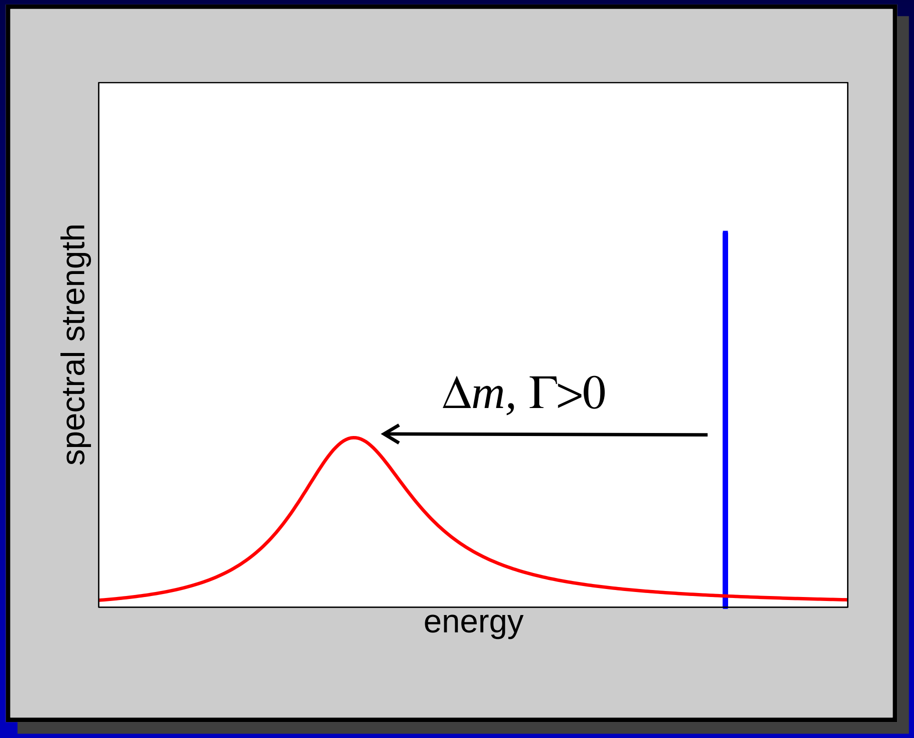
- Good quasi-particles: $Re\Sigma >> Im\Sigma$



Potential, mass shifts $\Longrightarrow$ standard transport (BUU,QMD,. . .)

Medium effects & transport

- Broad 'quasi'-particles: $Re\Sigma \sim Im\Sigma$

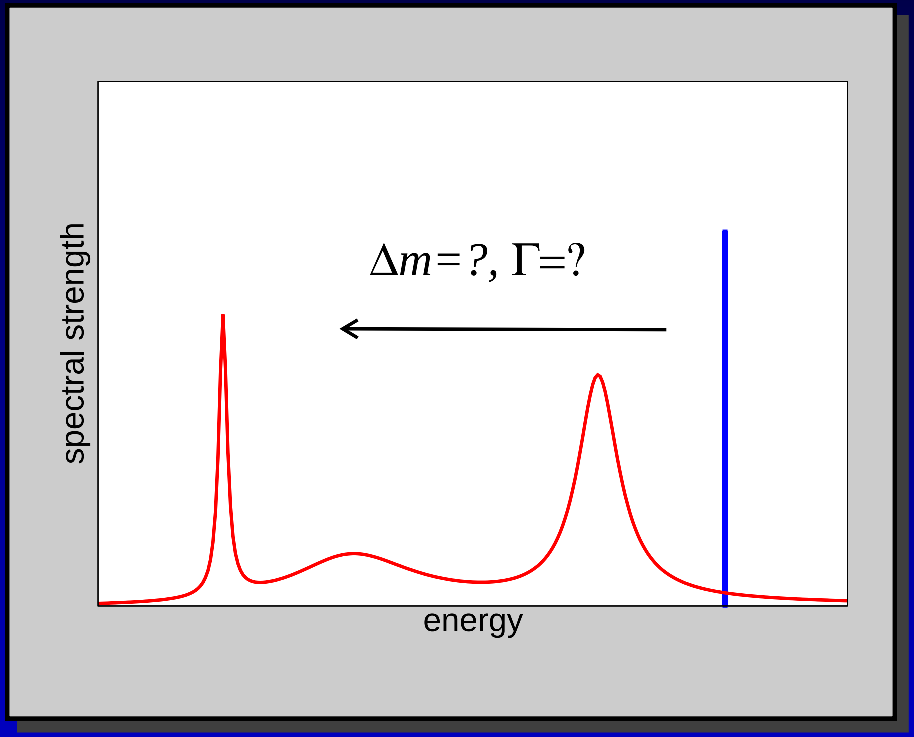


well defined Breit-Wigner $(\Gamma = \Gamma(\rho, k))$

$\Longrightarrow$ Extended quasi-particle - off-shell transport

Medium effects & transport

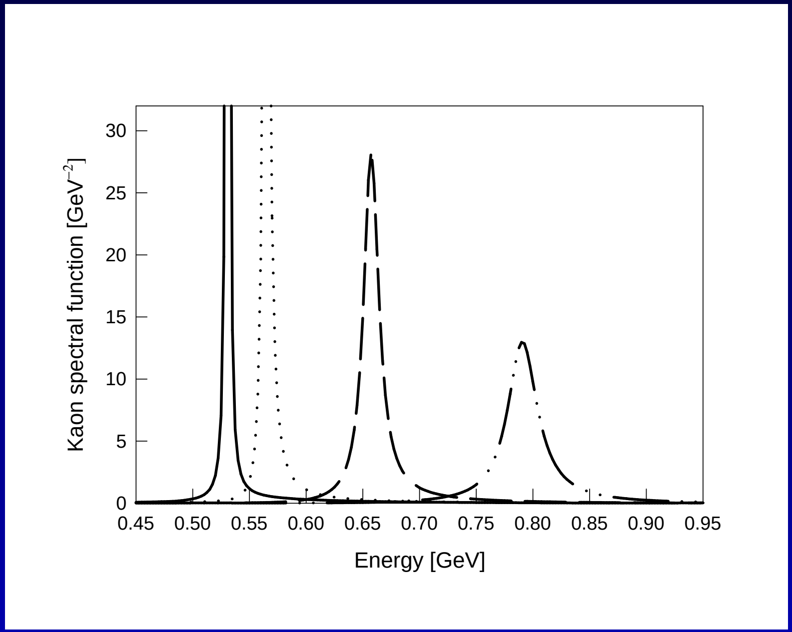
- Complex spectral function: $Im\Sigma = Im\Sigma(\rho, k)$

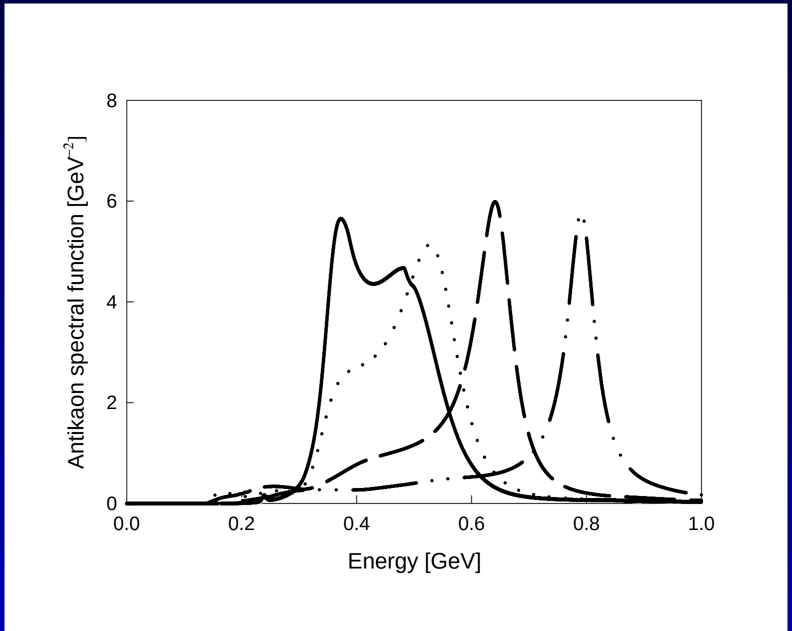


Multi-resonant spectral fucntion $\Longrightarrow$ no well defined Breit-Wigner $\Longrightarrow$ treatment not so clear

A typical example

- $K^{\pm}$ spectral functions



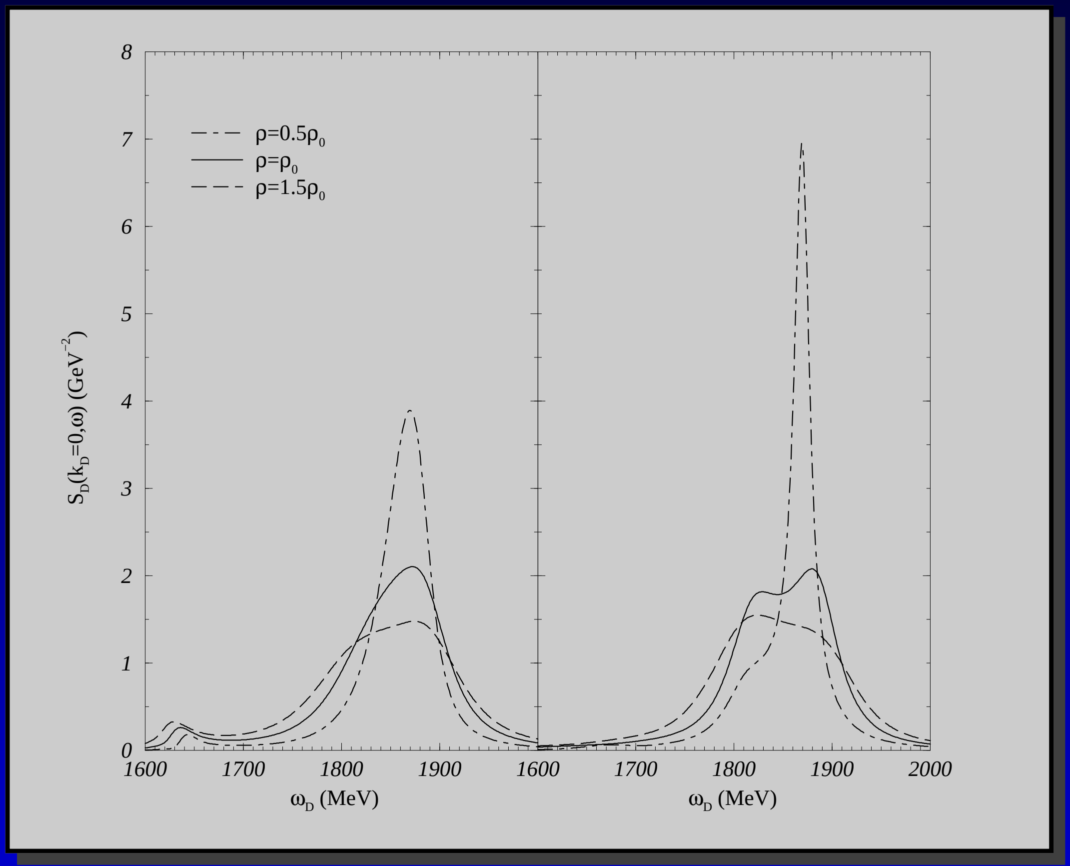


Coupled channel calculations from M. Lutz

K^{+}: non-resonant; K^{-}: resonant

D mesons

- D spectral functions



Coupled channel G-Matrix: Tolos et al., PRC 70 (2004) 025203

left: w/o, right with π and N dressing

Good quasi-particles

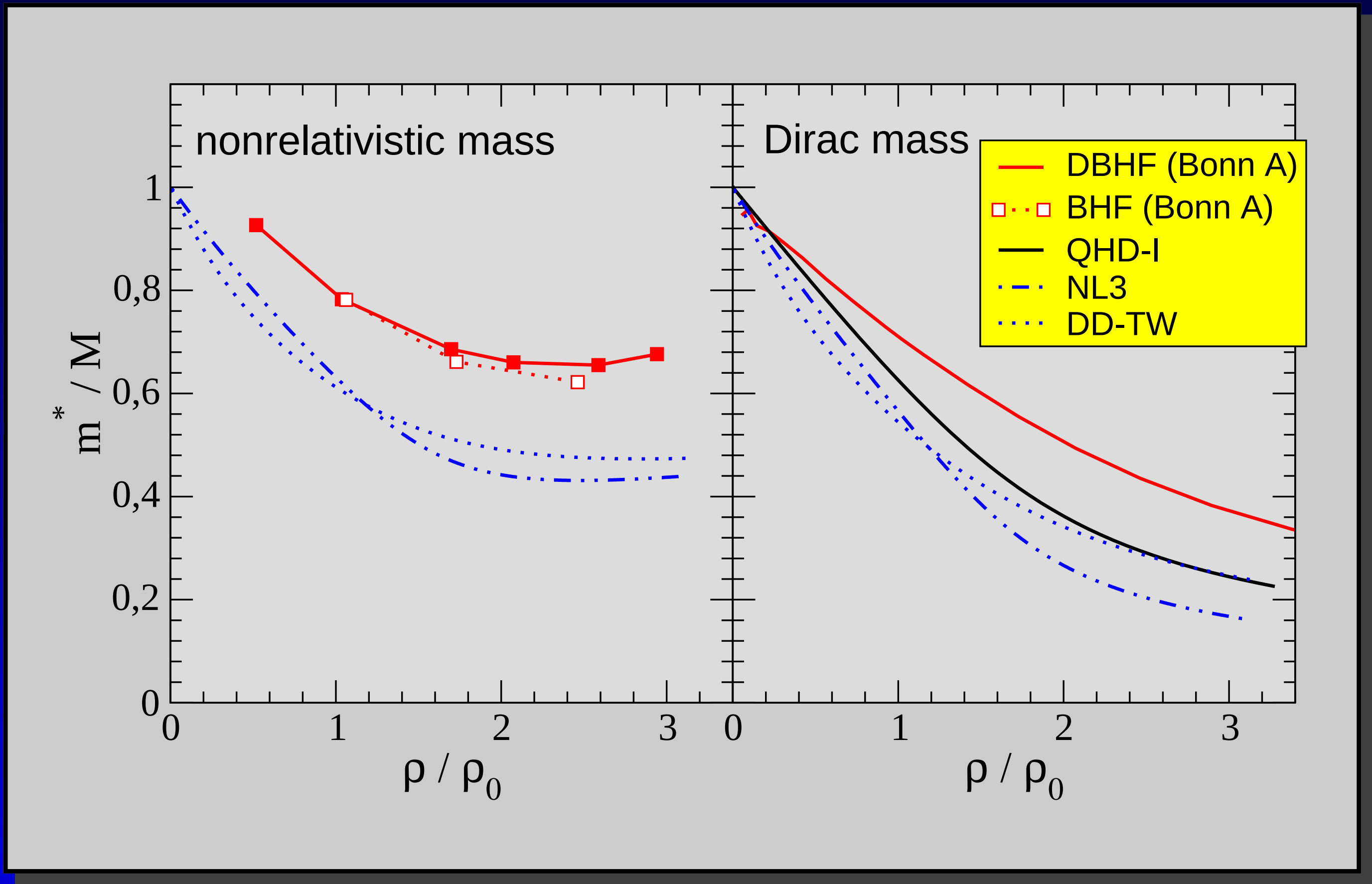
- Only $Re\Sigma(\rho, k)$ relevant
- Relativistic: scalar and vector part
- In-medium dispersion relation:

$$\omega = \sqrt{\vec{k}^2 + (M + S(\rho, k))^2} + V(\rho, k)$$

- Independent variables: $\vec{x}_i,\ \vec{k}_i$
- On-shell scattering $\Longrightarrow$ geometrical interpretation of cross sections
- Broad resonances: sample M according to BW, put particle on-shell

Examples

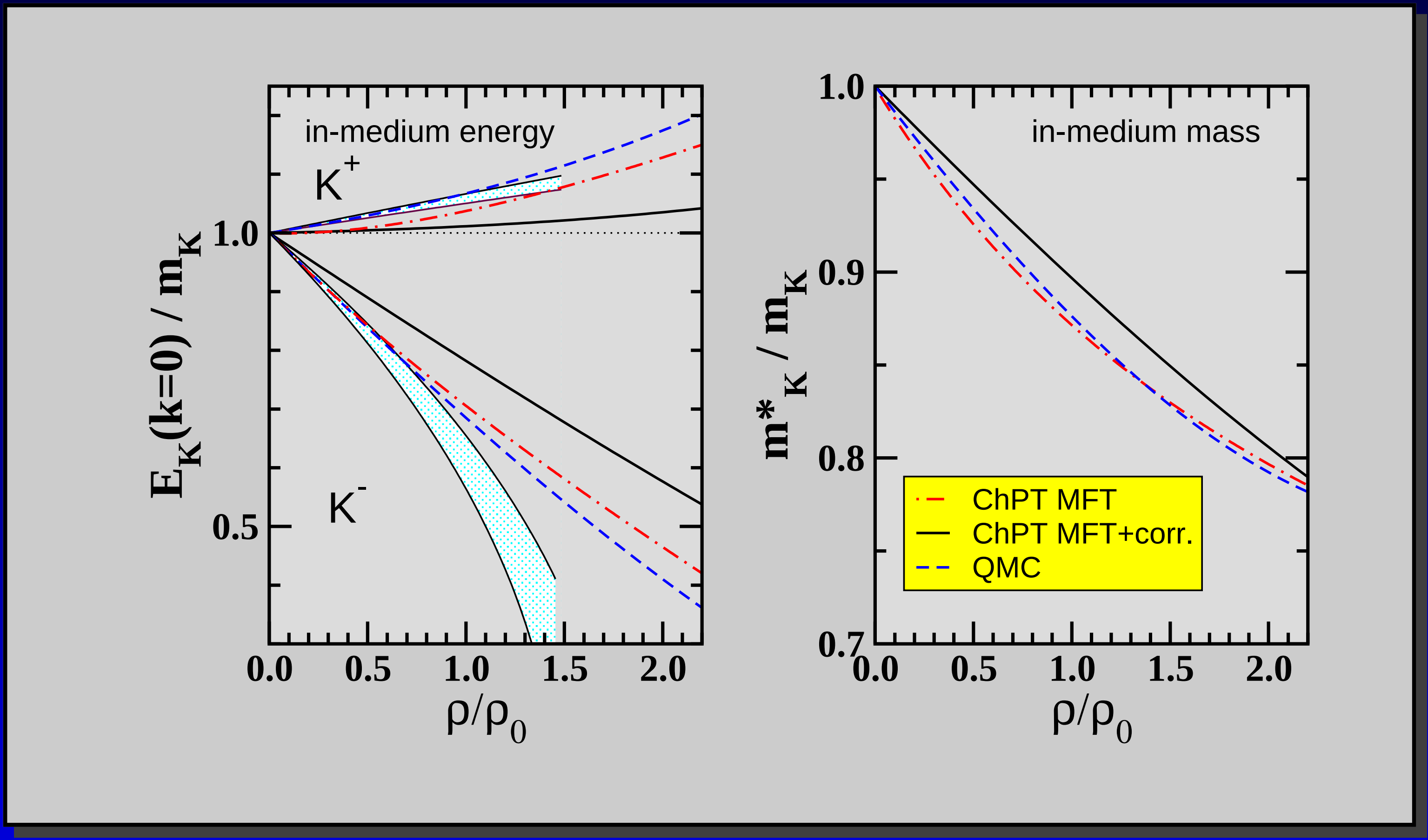
- Nucleons



DBHF: Fuchs et al., e.g. PRL 95 (2005) 022302

Examples

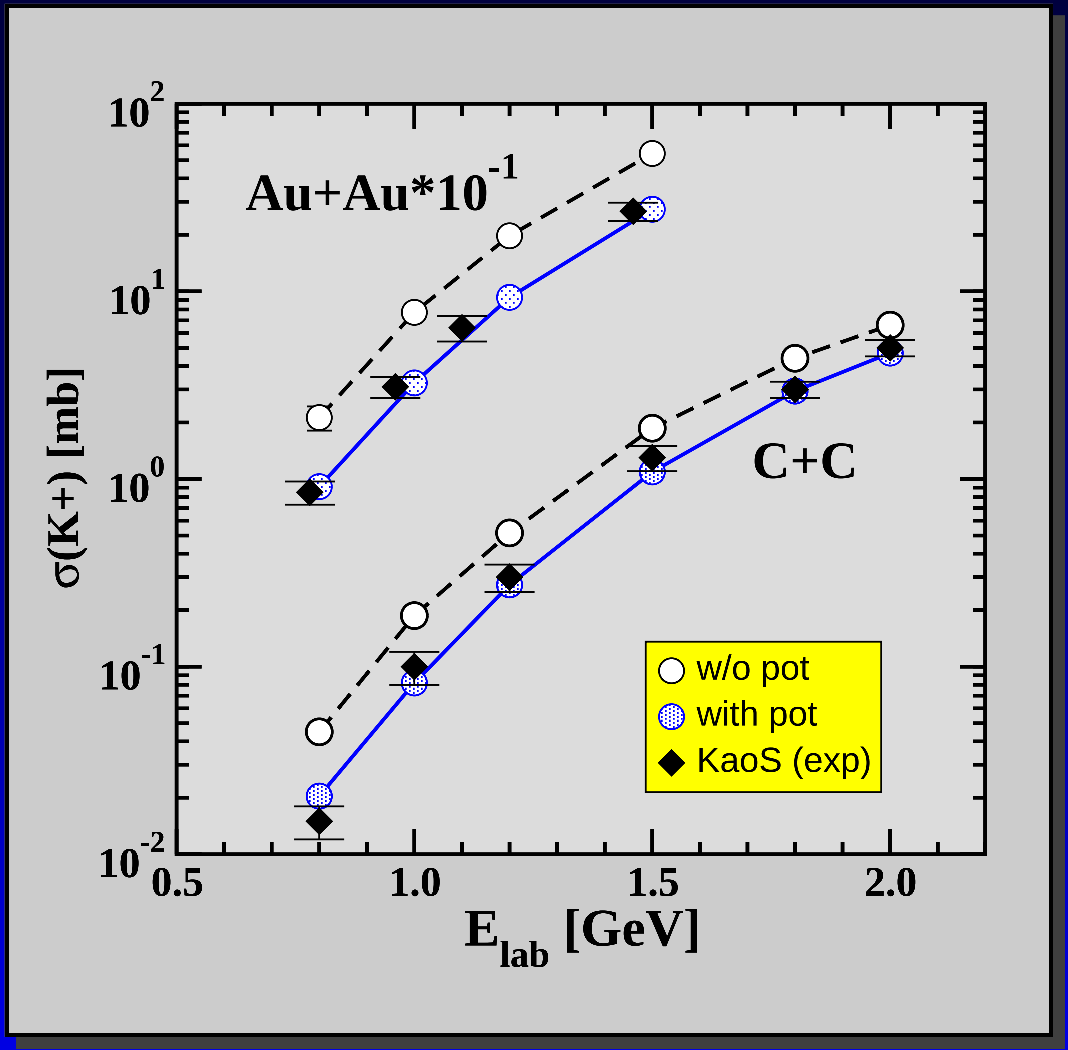
- Kaons



See e.g. C.F., Prog. Part. Nucl. Phys. 56 (2006) 1

Examples

- Kaons: transport results (QMD)

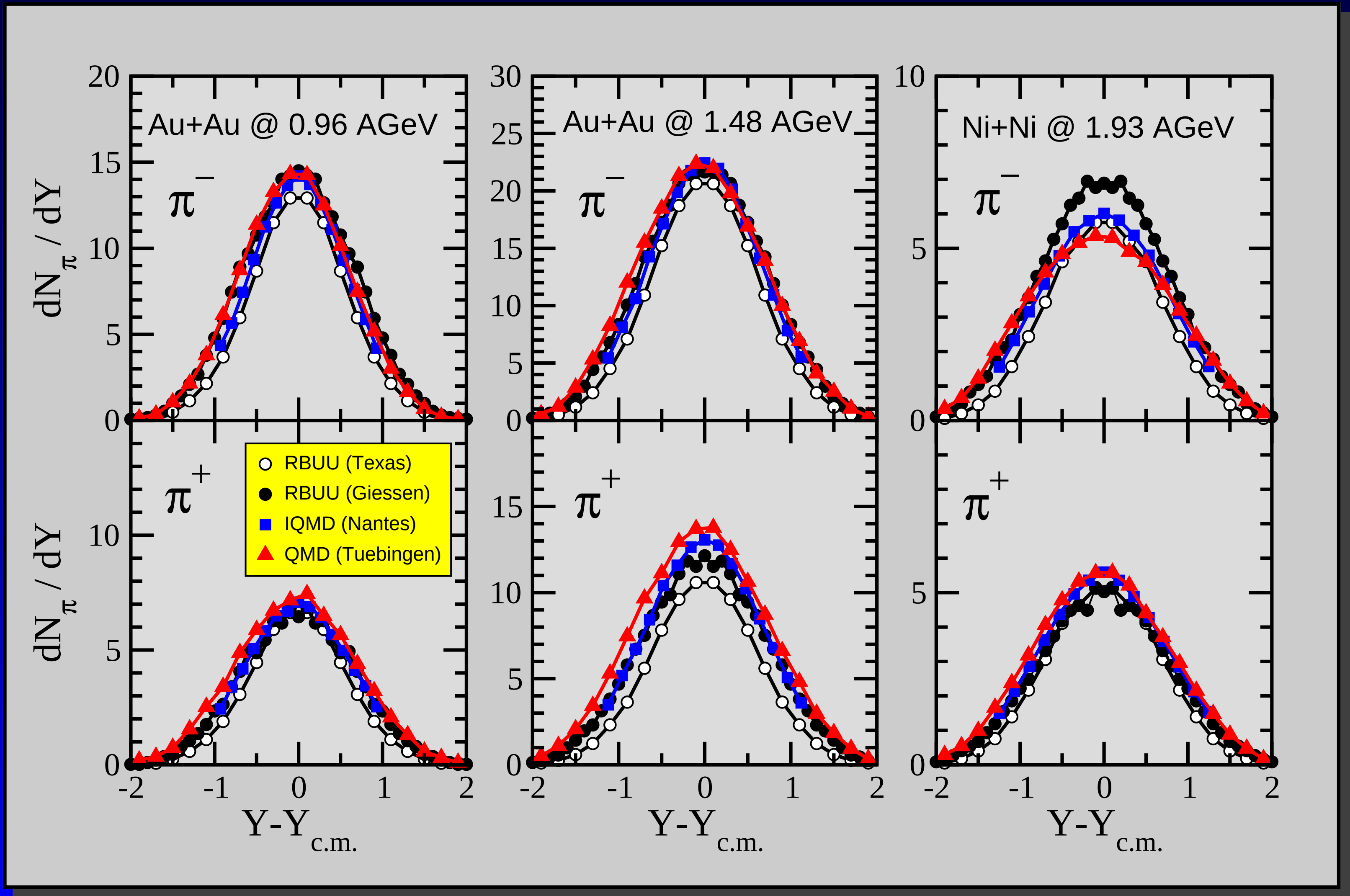


See e.g. C.F., Prog. Part. Nucl. Phys. 56 (2006) 1

Comparison of different codes

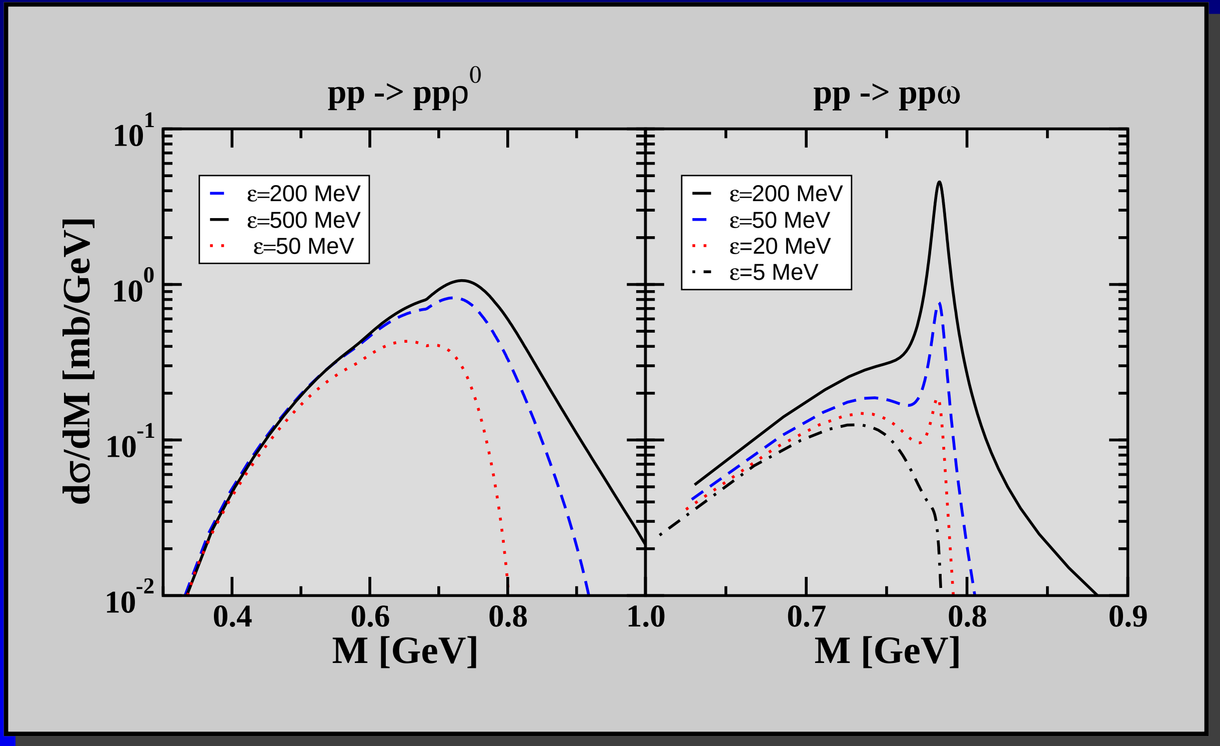
Workshop on transport models Trento, May 2003:

Kolomeistev et al., JPG 31 (2005) 741; C.F., PPNP 56 (2006) 1



Perturbative off-shell effects

- Full spectral functions ($Im\Sigma(\rho, k)$) in perturbative particle production
- Example: $R \rightarrow N + \rho, \omega(\rho, k) \rightarrow X + e^{+}e^{-}$
- Realization: QMD Tübingen



Dynamical off-shell effects

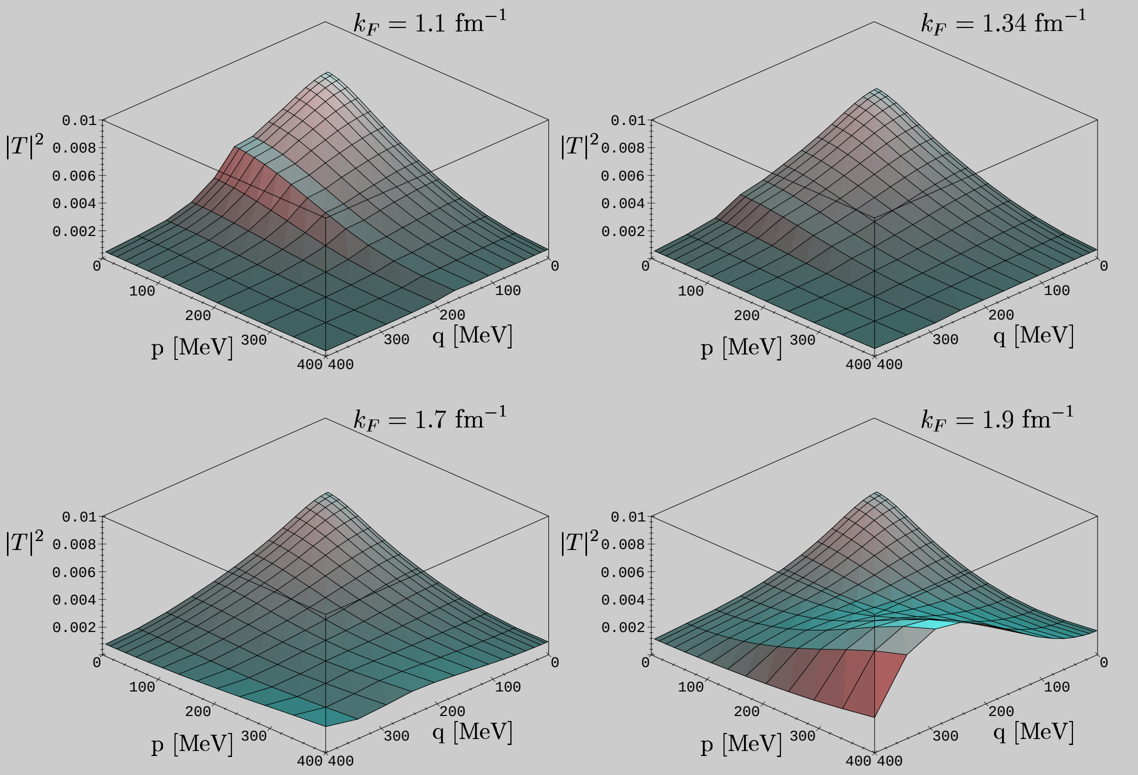
- First step towards off-shell transport
- Extended test-particle method: Leupold, Cassing/Juchem
- Independent variables: $\vec{x}_i,\ \vec{k}_i,\ \omega_i$
- Additional Eq. for off-shellness:

$$\frac{d}{dt}\Delta\omega_i = \frac{\Delta\omega_i}{\Gamma}\frac{d}{dt}\Gamma$$

- Collisions: On-shell cross sections are evaluated at off-shell energies $\omega_i + \Delta\omega_i$, geometrical interpretation is retained.
- Realization: RBUU Giessen, BUU Rossendorf
- But: knowledge of off-shell transition amplitudes required!

Examples

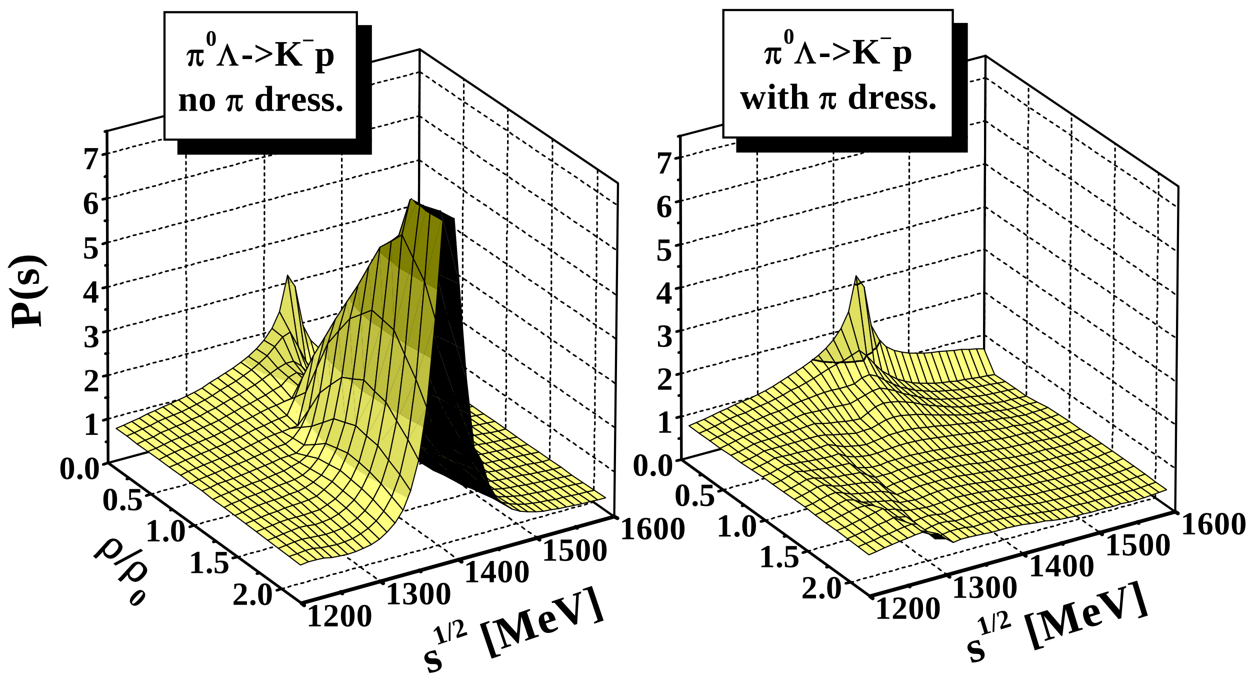
- NN half-off-shell matrix elements



DBHF: C.F. et al. PRC 64 (2001) 024003

Examples

- K^- absorption cross section

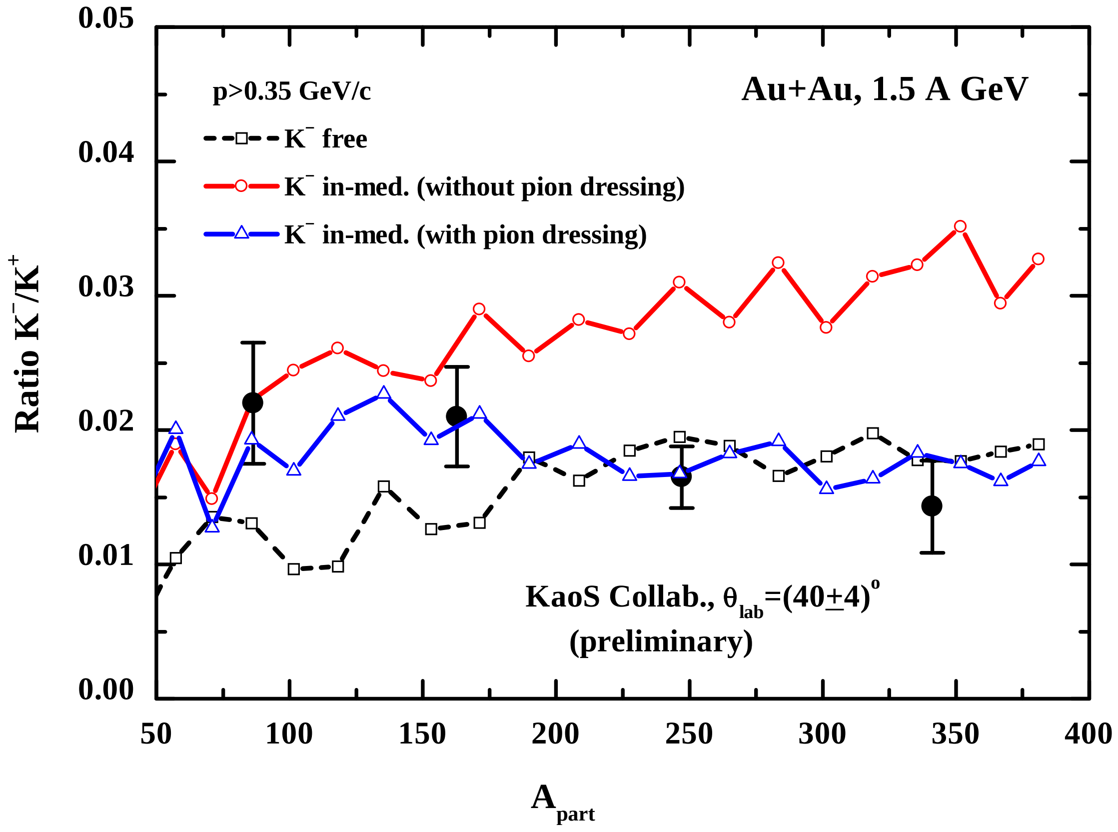


Coupled channel G-Matrix: Tolos et al.

Off-shell transport: Cassing et al., NPA 727 (2003) 59

Examples

- K^- in off-shell transport



Cassing et al., NPA 727 (2003) 59

Full quantum transport?

- Requires solution of quantum evolution equations (Kadanoff-Baym) in 7-dim. phase space ($\vec{x}, \vec{k}, \omega$)
- test-particles $\Longrightarrow$ 7-dim. lattice (symmetries $\Longrightarrow$ 5 dim.)
- cross sections $\Longrightarrow$ transition amplitudes
- First attempts:
  Köhler 1995: uniform system & toy model potential
  (local and Gaussian, i.e. $|V(\vec{k}-\vec{k}')|^2 = |V(\vec{k})|^2|V(\vec{k}')|^2$)

Summary

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- Standard transport:
  - Well defined in quasi-particle limit
  - State-of-the art codes agree for standard observables (N, π, K^+)
  - Large deviations for rare & off-shell probes (K^-, ρ, ω) $\Longrightarrow$ Common baseline required!

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- Standard transport:
  - Well defined in quasi-particle limit
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- Off-shell treatments:
  - Perturbative (no limits for spectral functions)
  - Dynamical $\Longrightarrow$ extended quasi-particle transport
  - Off-shell amplitudes to large extent unknown

Summary

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- Full Quantum transport?
  - test-particles $\Longrightarrow$ lattice
  - cross-sections $\Longrightarrow$ amplitudes

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- Full Quantum transport?
  - test-particles $\Longrightarrow$ lattice
  - cross-sections $\Longrightarrow$ amplitudes
- Problem: missing manpower & support