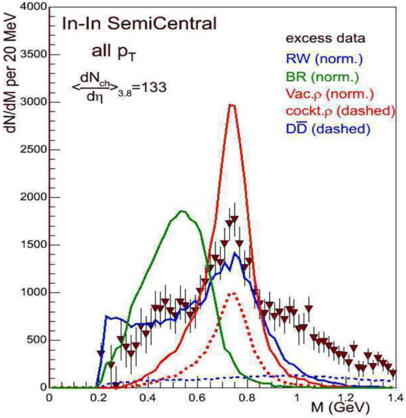
In-medium changes of properties of hadrons



dilepton spectrum from a nucleus-nucleus collision

models:

- dropping mass
- broad spectral function

data: NA60

S. Damjanovic et al. (NA60), Nucl. Phys. A 774, 715 (2006)

Dileptons, hadronic resonances and chiral symmetry

Established connections and missing links

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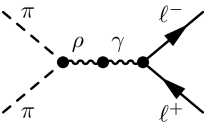
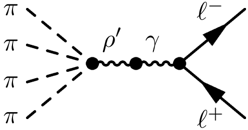
[2]Giessen University

CPOD, GSI, Darmstadt, July 2007

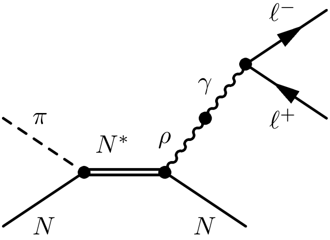
Four generic processes

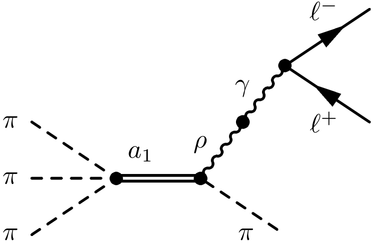




$$\pi + \pi \to {\color{red}\rho} \to \ell^+\ell^- \qquad 4\pi \to {\color{red}\rho'} \to \ell^+\ell^-$$

$$\pi + N \to {\color{red}N^*} \to \ell^+\ell^- + N \qquad 3\pi \to {\color{red}a_1} \to \ell^+\ell^- + \pi$$





Four generic processes

from conceptual/technical point of view on equal level:

1. $\pi + \pi \to \ell^+\ell^-$ and $4\pi \to \ell^+\ell^-$
   - both known from back reaction in vacuum
   - total invariant mass of hadrons = invariant mass of dilepton
2. $\pi + N \to \ell^+\ell^- + N$ and $3\pi \to \ell^+\ell^- + \pi$
   - both scattering of dilepton on one medium constituent
   - total invariant mass of hadrons does not translate to invariant mass of dilepton (Dalitz decay)

   $\hookrightarrow$ populate especially low invariant masses

   $\hookrightarrow$ low mass enhancement

from point of view of production on equal level:

1. $\pi + \pi \to \ell^+\ell^-$ and $\pi + N \to \ell^+\ell^- + N$
   - both two-body reactions (and both genuine “in-medium”)
2. $4\pi \to \ell^+\ell^-$ and $3\pi \to \ell^+\ell^- + \pi$
   - both N-body reactions (N$>$2)

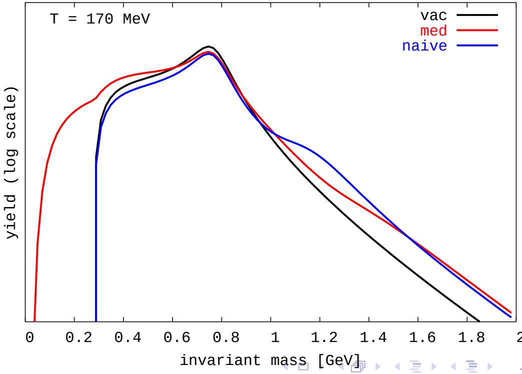
Importance of the four generic processes

- $\pi + \pi \to \ell^+\ell^-$: important in ρ-meson region
- $4\pi \to \ell^+\ell^-$: important above 1 GeV (cf. Rapp/van Hees, PRL 2006)
- $\pi + N \to \ell^+\ell^- + N$: low-mass enhancement
- $3\pi \to \ell^+\ell^- + \pi$: conceptually interesting (chiral mixing) (cf. Steele/Yamagishi/Zahed, PLB 384 (1996) 255)

naive expectation: appearance of a_1 peak

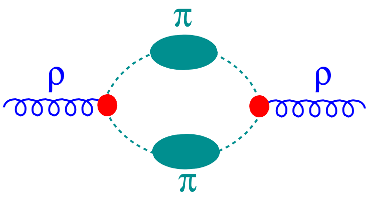
correct: strength at low masses (Dalitz decay)

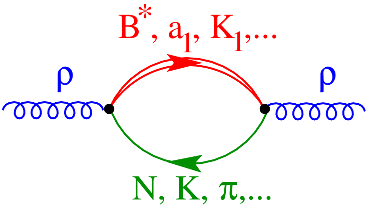
quantitatively not very large



Hadronic many-body theory

- HMBT for vector mesons [Ko et al, Chanfray et al, Herrmann et al, Rapp et al, ...]
- $\pi\pi$ interactions and baryonic excitations





- +corresponding vertex corrections ⇔ gauge invariance
- Baryon (resonances) important, even at RHIC with low **net** baryon density $n_B - n_{\bar{B}}$
- reason: $n_B + n_{\bar{B}}$ relevant (CP inv. of strong interactions)

Required input for hadronic models

central quantity (at least in equilibrium):

- spectral function

$\hookrightarrow$ need contributions to self energy from various processes

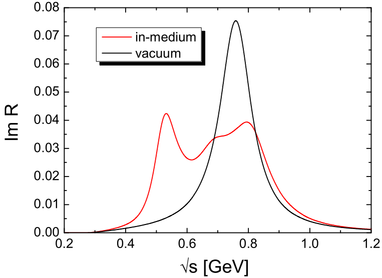
elementary input:

1. (hadronic) decays of vector mesons
2. scattering of vector mesons on medium constituents (pions, nucleons, ...)
   $\rightsquigarrow$ related to Dalitz decays = inverse reaction

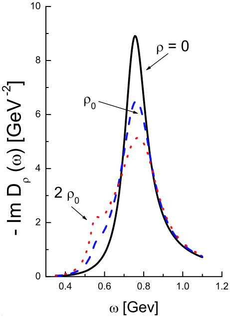
how well do we know input?

1. decays from $e^+e^- \rightarrow$ vector meson $\rightarrow$ hadrons
2. scattering: so far sizable model dependences

Hadronic models for the rho meson in nuclear matter



Post/Leupold/Mosel,
NPA 741, 81 (2004)



Lutz/Wolf/Friman,
NPA 706, 431 (2002)

Toy model for ρ-meson spectral function

- self energy $\Pi(q) = \Pi_{2\pi}(q) + \Pi_{N^* N^{-1}}(q)$
- spectral function

$$\mathcal{A}(q) = -\mathrm{Im}\frac{1}{q^2 - m_\rho^2 - \Pi(q)}$$

$$= \frac{-\mathrm{Im}\Pi(q)}{[q^2 - m_\rho^2 - \mathrm{Re}\Pi(q)]^2 + [\mathrm{Im}\Pi(q)]^2}$$

$$= -\frac{\mathrm{Im}\Pi_{2\pi}(q)}{[\ldots]^2 + [\ldots]^2} - \frac{\mathrm{Im}\Pi_{N^* N^{-1}}(q)}{[\ldots]^2 + [\ldots]^2}$$

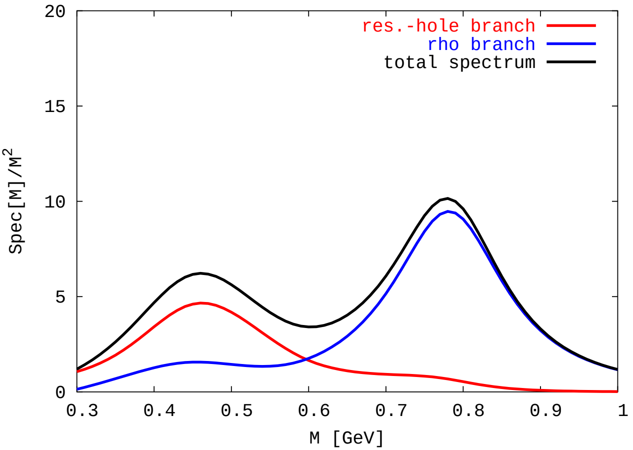
- how to get back elementary two-body reactions? (=traditional transport)

$\leadsto$ replace in denominator $\Pi \to \Pi_{\mathrm{vac}} \approx \Pi_{2\pi}$ (violates unitarity)

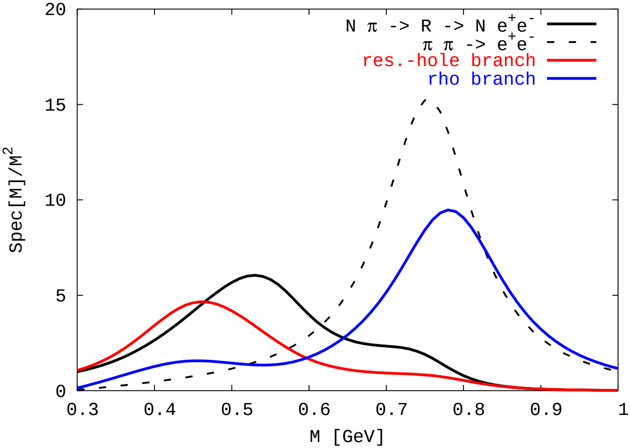
Spectral information including unitarization

Decomposition:

- genuine ρ-meson branch (2π)
- resonance-hole branch



Elementary versus unitarized contributions



$(\vec{q} = 0)$

- sum of colored curves (contributions unitarized) different from sum of black curves (elementary)
- especially: level repulsion, depletion of ρ-meson peak

Elementary versus unitarized contributions

- unitarized effects different from pure two-body reactions
- especially: level repulsion, depletion of ρ-meson peak
- but: strength at low invariant masses already from two-body reactions $\pi N \to R \to \ell^+\ell^- N$, i.e. Dalitz decays

$\rightsquigarrow$ need good resolution to distinguish

Outlook

missing links:

- further justifi cations for resonance scenario
- models for chiral restoration including transition, not only way towards it

$\hookrightarrow$ inclusion of chiral restoration simpler in schematic models, more complicated for more realistic ones

- explore further connection between vacuum properties of resonances and chiral symmetry breaking

$\hookrightarrow$ measure elementary dilepton production, especially $\pi N \to \ell^+ \ell^- N$

- explore many-body aspects in heavy-ion reactions (unitarization, resummation methods)

Electromagnetic spectra at the CERN-SPS

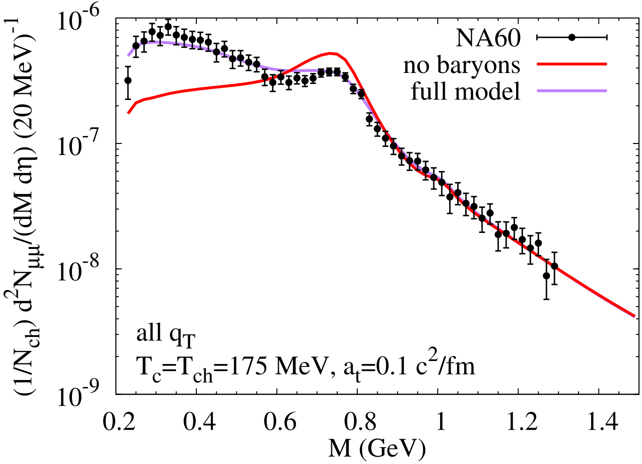
Hendrik van Hees

Goethe-Universität Frankfurt

May 21, 2013

Importance of baryon effects

- Baryonic interactions important!
- in-medium broadening
- low-mass tail!



Dilepton Signal from GiBUU Transport Model

Janus Weil

Frankfurt Institute for Advanced Studies

in collab. with: U. Mosel, H. van Hees, K. Gallmeister, S. Endres, M. Bleicher

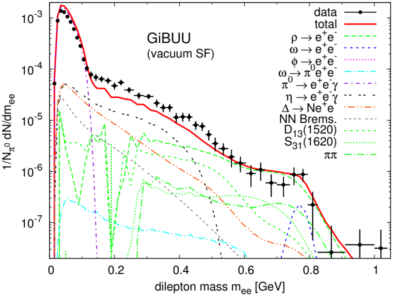
Workshop on
Electromagnetic Probes of Strongly Interacting Matter
ECT* Trento, May 20, 2013

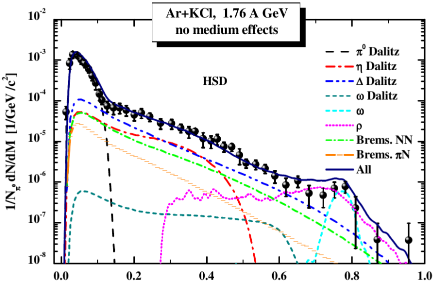
FIAS Frankfurt Institute for Advanced Studies

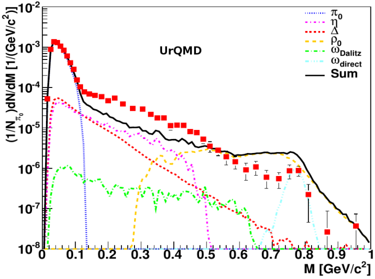
HIC for FAIR
Helmholtz International Center

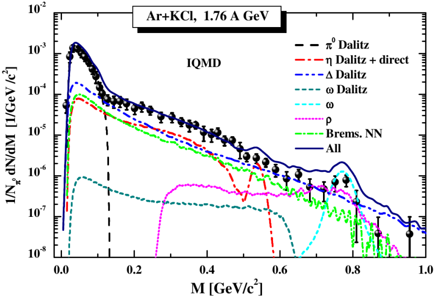
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Ar + KCl @ 1.76: status (aka the "Δ puzzle")







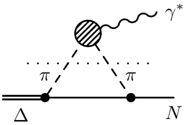


Questions

- Is a 'vacuum' cocktail sufficient to describe the ArKCl spectrum?
- Is there hope to see any modifications of the ρ spec. func.?
- answers currently depend on which model you believe in ...
- biggest discrepancy: Δ Dalitz channel

- $\Rightarrow$ we need to check very carefully if we understand the cocktail with all its contributions
- separating vacuum cocktail from medium modifications requires two steps:
  1. fix vacuum cocktail & model input via elementary collisions only!
  2. only afterwards: check if the same cocktail can describe heavy-ion collisions (or if medium-mod. are required)

Where to get the information from?



(pion cloud)

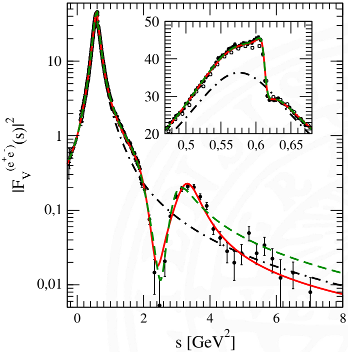
- $\Delta \to \pi\,\pi\,N$:

$\hookrightarrow$ e.g. from data on $\pi\,N \to \Delta \to \pi\,\pi\,N$

$\hookrightarrow$ HADES pion beam can improve data basis

- $\pi\,\pi \to \gamma^*$:

$\hookrightarrow$ pion form factor, very well known



Hanhart, Phys.Lett. B715 (2012) 170