Dilepton Signal from GiBUU Transport Model

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FIAS Frankfurt Institute for Advanced Studies

HIC for FAIR
Helmholtz International Center

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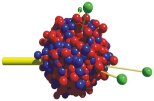
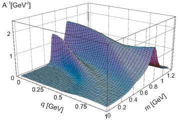
Introduction

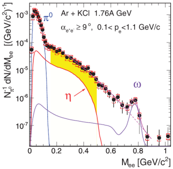
- HADES has measured various dilepton spectra in the few-GeV regime (1-4 GeV):
  - elementary reactions (pp, dp, pNb)
  - heavy-ion collisions (CC, ArKCl, AuAu)
- We need models (e.g. transport) to interpret & understand them!
- What do we want to learn?
  $\Rightarrow$ in-medium spectral functions
  (in particular for the ρ meson)
- heaviest system so far: Ar+KCl at 1.76 GeV
  ($\rho \lesssim 3\rho_0$, $T \sim 80\,\mathrm{MeV}$)
- What is the current status?

HADES

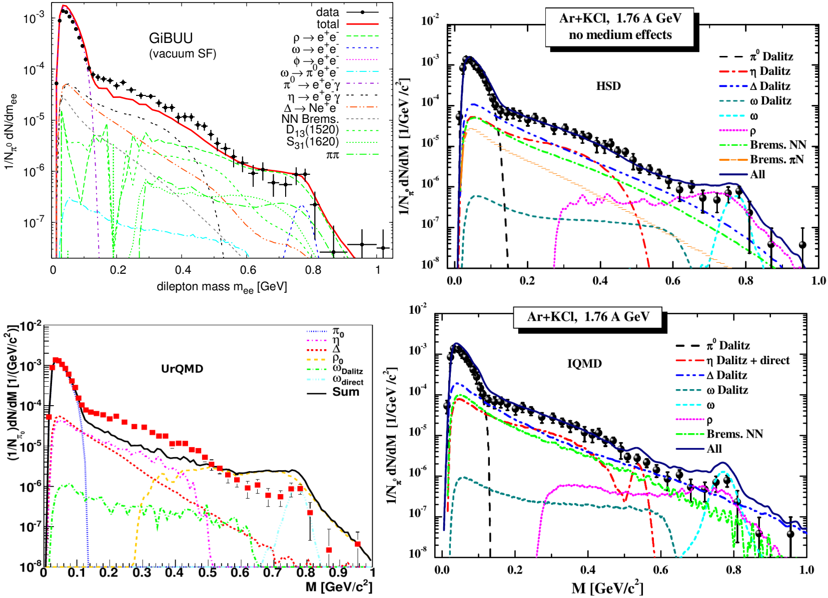


GiBUU





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

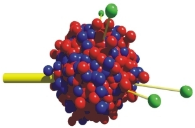
- $\Rightarrow$ we need to check very carefully if we understand the cocktail with all its contributions
- separating vacuum cocktail from medium modifications requires two steps:
  1. fix vacuum cocktail & model input via elementary collisions only!
  2. only afterwards: check if the same cocktail can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

The GiBUU Transport Model

- hadronic transport model (microscopic, non-equilibrium)
- unified framework for various types of reactions (γA, eA, νA, pA, πA, AA) and observables
- BUU equ.: space-time evolution of phase-space density F (via gradient expansion from Kadanoff-Baym)

$$\frac{\partial(p_0 - H)}{\partial p_\mu}\frac{\partial F(x,p)}{\partial x^\mu} - \frac{\partial(p_0 - H)}{\partial x_\mu}\frac{\partial F(x,p)}{\partial p^\mu} = C(x,p)$$

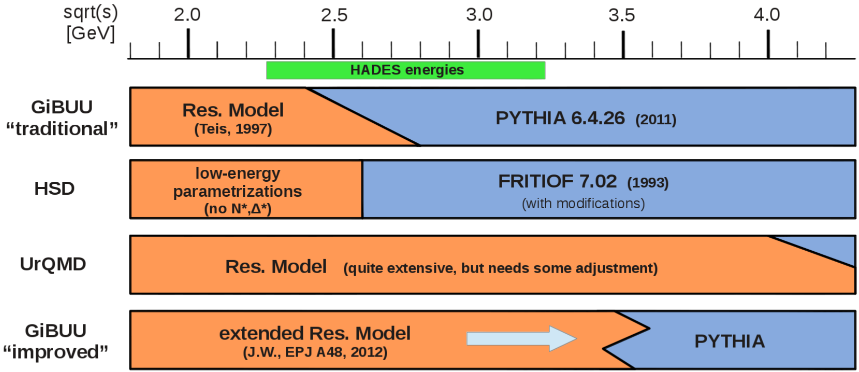
- Hamiltonian H:
  - hadronic mean fields, Coulomb, "off-shell potential"
- collision term $C(x,p)$: decays and collisions
  - low energy: resonance model, high energy: string fragment.
- O. Buss et al., Phys. Rep. 512 (2012), http://gibuu.physik.uni-giessen.de



GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project

Modeling collisions in the few-GeV regime

- baryon-baryon collisions at low energies: resonance models vs. string fragmentation

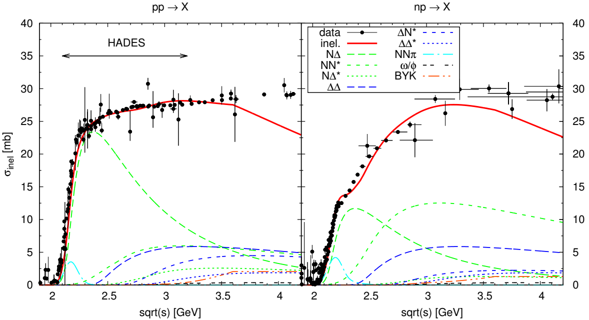


- HADES energy range is clearly in the resonance regime!
- we need one consistent model for the whole energy range!

Resonance Model

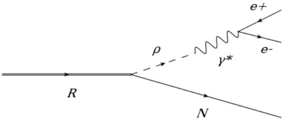
- assumption: inel. NN cross section is dominated by production and decay of baryonic resonances
- $NN \to NR, \Delta R$ (R : Δ, 7 N^* and 6 Δ^* states)
- based on Teis RM [Z. Phys. A 356, 1997] with several extensions
- all resonance parameters taken from Manley/Saleski PWA
- good descr. of total NN cross sections up to $\sqrt{s} \approx 3.5\,GeV$
- all π, η and ρ mesons produced via R decays (ω, ϕ: non-res.)

	rating	M_0 [MeV]	Γ_0 [MeV]
$P_{11}(1440)$	****	1462	391
$S_{11}(1535)$	***	1534	151
$S_{11}(1650)$	****	1659	173
$D_{13}(1520)$	****	1524	124
$D_{15}(1675)$	****	1676	159
$P_{13}(1720)$	*	1717	383
$F_{15}(1680)$	****	1684	139
$P_{33}(1232)$	****	1232	118
$S_{31}(1620)$	**	1672	154
$D_{33}(1700)$	*	1762	599
$P_{31}(1910)$	****	1882	239
$P_{33}(1600)$	***	1706	430
$F_{35}(1905)$	***	1881	327
$F_{37}(1950)$	****	1945	300



Dilepton sources

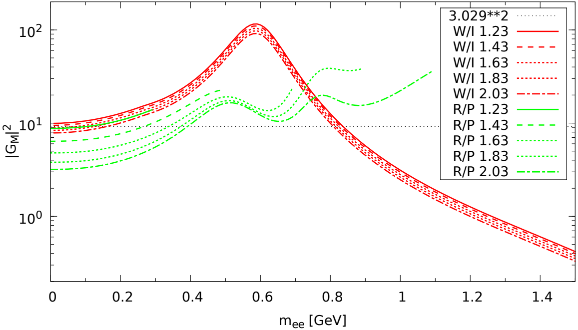
- $V \to e^+e^-$ (with $V = \rho, \omega, \phi$) via strict VMD: $\Gamma_{ee}(m) \propto m^{-3}$
- $P \to \gamma e^+e^-$ (with $P = \pi^0, \eta, \eta'$) [Landsberg, Phys.Rep.128, 1985]
- $\omega \to \pi^0 e^+e^-$ [Landsberg]
- $\Delta \to Ne^+e^-$ [Krivoruchenko, Phys.Rev.D65, 2002], em. transition form factor from Ramalho/Pena [Phys.Rev.D85, 2012]
- baryonic resonances N^*, Δ^*: two-step decay $R \to \rho N \to e^+e^-N$
  $\Rightarrow$ dilepton contributions from all res. which have a ρ coupling (with an 'implicit' FF: strict VMD)



- Bremsstrahlung in soft-photon approximation

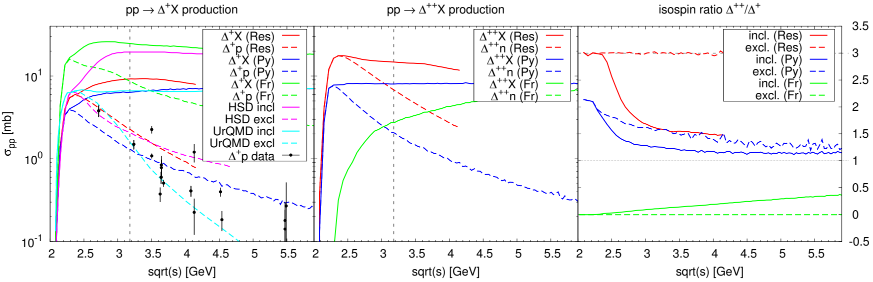
Delta form factor

- electromagnetic N-Δ transition form factor only constrained by data in space-like region
- experimentally unknown in time-like region
- recent models: Wan/Iachello (red, IJMP A20, 2005), Ramalho/Pena (green, PRD85, 2012)



Δ production cross section

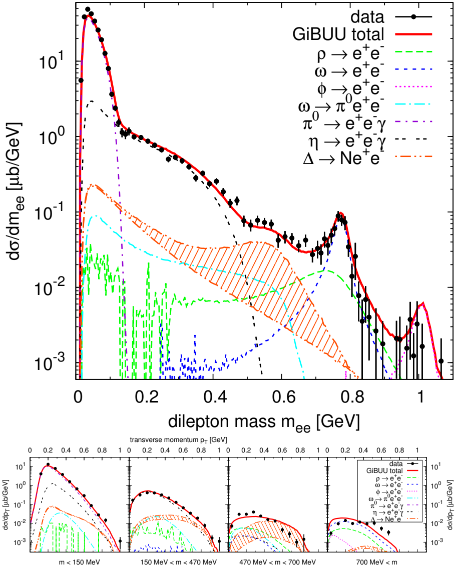
- only exclusive Δ^+ production constrained by data
- resonance models (UrQMD/GiBUU) agree roughly on inclusive production
- but: inclusive cross section much larger in HSD/FRITIOF
- string models do not obey isospin relations!



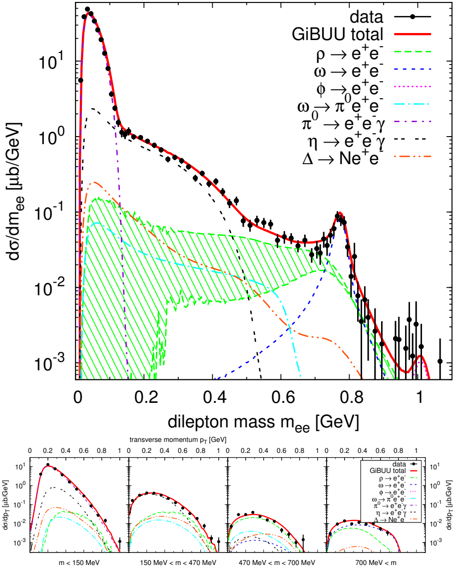
lesson: don't trust string fragmentation models at low energies!

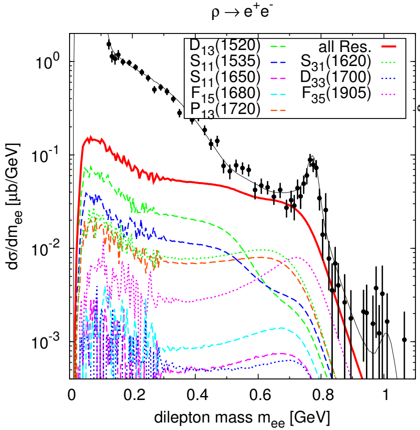
p+p at 3.5 GeV

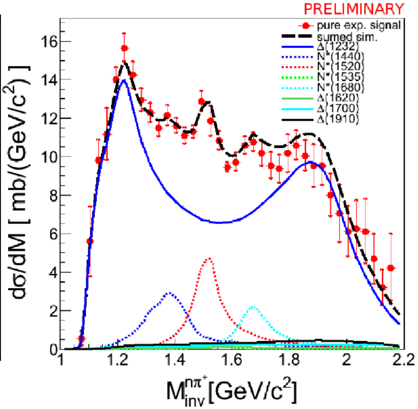
Pythia + Iachello FF



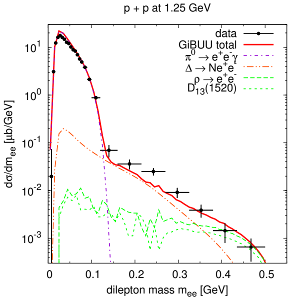
Resonance Model + Ramalho FF

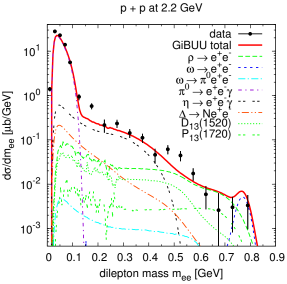


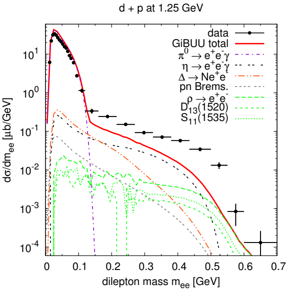




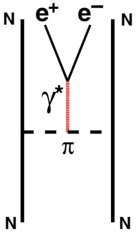
- in the resonance model approach we get large contributions from several N^* and Δ^* resonances
- πN spectra confirm significant resonance contr. (A. Dybczak)

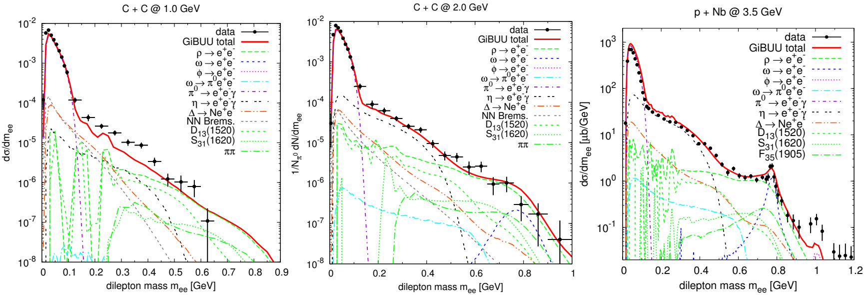






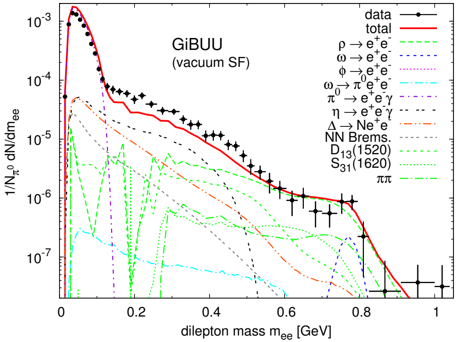
- p+p at 1.25 and 2.2 GeV rather well described
- large underestimation in d+p
- OBE models can help to understand isospin effects (Shyam/Mosel, PRC82, 2010)

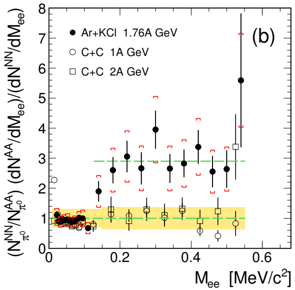




- C+C is a light system, can be described roughly by a superposition of NN collisions
- 2 GeV data well described, some discrepancies at 1 GeV
- also p+Nb well reproduced, based on the good agreement with p+p@3.5

Ar + KCl @ 1.76 AGeV





- Ar+KCl data shows excess over NN/CC ($\sim$ factor 3)
- GiBUU with vac. SF misses data
  $\Rightarrow$ room for medium mod.

Ar+KCl: off-shell transport

off-shell EOM for test particles
[Cassing/Juchem (NPA 665, 2000),

Leupold (NPA 672, 2000)]:

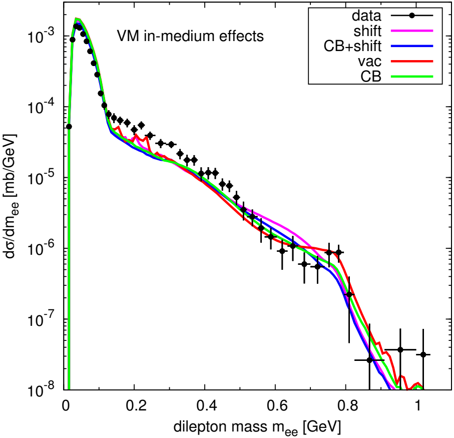
$$\dot{\vec{r}}_i = \frac{1}{1-C_i}\frac{1}{2E_i}\left[2\vec{p}_i + \frac{\partial}{\partial\vec{p}_i}Re(\Sigma_i) + \chi_i\frac{\partial\Gamma_i}{\partial\vec{p}_i}\right],$$

$$\dot{\vec{p}}_i = -\frac{1}{1-C_i}\frac{1}{2E_i}\left[\frac{\partial}{\partial\vec{r}_i}Re(\Sigma_i) + \chi_i\frac{\partial\Gamma_i}{\partial\vec{r}_i}\right],$$

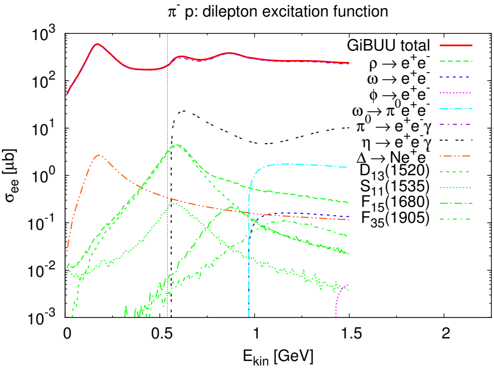
$$C_i = \frac{1}{2E_i}\left[\frac{\partial}{\partial E_i}Re(\Sigma_i) + \chi_i\frac{\partial\Gamma_i}{\partial E_i}\right],$$

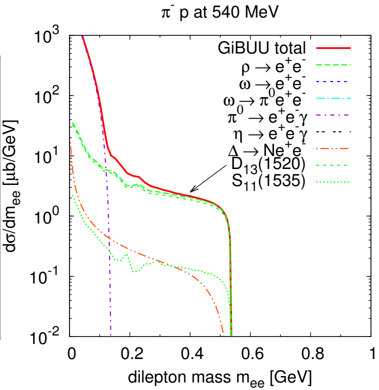
$$\chi_i = \frac{m_i^2 - M^2}{\Gamma_i}, \quad \frac{d\chi_i}{dt} = 0$$

- test particles dynamically change their masses
- some approximations required
- only works 'close to mass shell'



PION-INDUCED REACTIONS





- biggest opportunity: directly determine dilepton contribution from $N^*(1520)$, including form factor!
- but: pion beam will actually not help to solve the "Δ puzzle"!
- prev. calculations by Weidmann (PRC59, 1999) and Effenberger (PRC60, 1999)

Conclusions

1. resonance-model approach provides good description of most elementary dilepton data (as well as C+C)
2. contributions of N^* and Δ^* resonances are significant!
3. better constraints on resonance parameters needed ($\Rightarrow$ pion beam at GSI!)
4. future investigations of in-medium effects:
    - off-shell transport (GiBUU)
    - coarse graining (UrQMD)
5. stop the black-boxing! we need open models!