Low-mass dileptons at HADES and CBM in a transport approach

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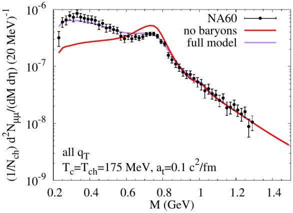
Outline

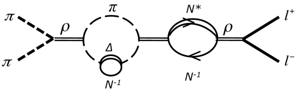
questions & topics to be addressed in this talk:

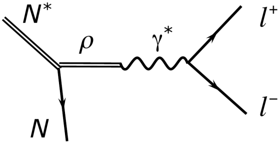
- what is so tough about dileptons at low energies?
- what is the current status w.r.t. the HADES results?
- how do transport models help to understand them?
- what are the limitations and challenges?
- what have we learned from HADES?
- what does it mean for CBM?

Intro

- dileptons at high energies (NA60 etc):
  - vacuum spectra dominated by mesons
  - ρ gets broad in medium, coupling to baryons plays an important role
- at lower energies (HADES, DLS):
  - baryons become more important (already in vacuum cocktail)
  - bremsstrahlung, interference effects, ...
  - how do baryons couple to em. sector? (how to describe $R \to e^+e^-N$?)
- baryon effects connect vacuum spectra at low energies to in-medium spectra at high energies!
- CBM bridges the energy region between SIS(18) and SPS, will be essential to create a consistent picture







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.hepforge.org

GiBUU

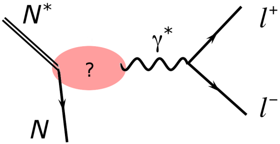
The Giessen Boltzmann-Uehling-Uhlenbeck Project

$R \to e^+e^-N$: the 'traditional' treatment

- $R = \Delta, N^*, \Delta^*$
- photon couplings ($R \to \gamma N$) known from photoproduction experiments ($\gamma N \to X$)
- extend to time-like region ($R \to \gamma^* N$) via em. transition form factor (Wolf et al, Krivoruchenko et al.):

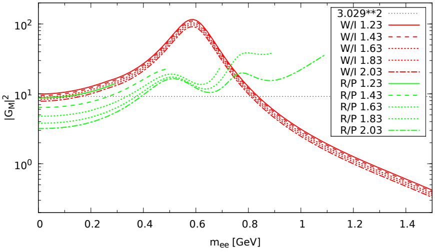
$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\mu} = \frac{2\alpha}{3\pi\mu}\frac{\alpha}{16}\frac{(m_R+m_N)^2}{m_R^3 m_N^2}\sqrt{(m_R+m_N)^2-\mu^2}\left[(m_R-m_N)^2-\mu^2\right]^{3/2}|F(\mu,m_R)|^2$$

- problem: form factor basically unknown, often neglected
- but: surely contains some relevant physics!



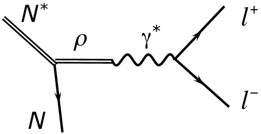
FORM FACTORS

- 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)
- no clear picture, large disagreements & uncertainties



OUR APPROACH

- first reasonable guess for form factor: vector-meson dominance! $R \to \rho N \to e^+e^- N$



- do decay in two steps: 1) $R \to \rho N$, 2) $\rho \to e^+e^-$
- transport-typical treatment: intermediate ρ is propagated, can rescatter etc
- assume **strict** VMD: R couples to γ^* **only** via ρ!
- (probably not the final solution, but represents a simple hypothesis that can be tested by data)
- includes the full kinematics of the decay (important: m_R dependence)

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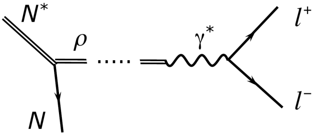

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RESONANCE MODEL

- $R \to \rho N$ couplings taken from:
  Manley/Saleski, Phys. Rev. D 45 (1992)
- (just like all other resonance parameters and decay modes)
- PWA including $\pi N \to \pi N$ and $\pi N \to 2\pi N$ data

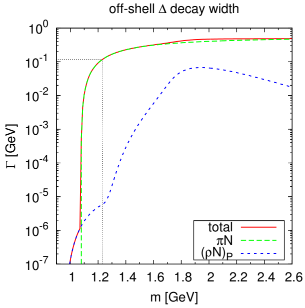
		M_0	Γ_0	$\lvert\mathcal{M}^2\rvert/16\pi$ [mb GeV^2]		branching ratio in %						
	rating	[MeV]	[MeV]	NR	ΔR	πN	ηN	$\pi\Delta$	ρN	σN	$\pi N^*(1440)$	$\sigma\Delta$
$P_{11}(1440)$	****	1462	391	70	—	69	—	22_P	—	9	—	—
$S_{11}(1535)$	***	1534	151	8	60	51	43	—	$2_S + 1_D$	1	2	—
$S_{11}(1650)$	****	1659	173	4	12	89	3	2_D	3_D	2	1	—
$D_{13}(1520)$	****	1524	124	4	12	59	—	$5_S + 15_D$	21_S	—	—	—
$D_{15}(1675)$	****	1676	159	17	—	47	—	53_D	—	—	—	—
$P_{13}(1720)$	*	1717	383	4	12	13	—	—	87_P	—	—	—
$F_{15}(1680)$	****	1684	139	4	12	70	—	$10_P + 1_F$	$5_P + 2_F$	12	—	—
$P_{33}(1232)$	****	1232	118	OBE	210	100	—	—	—	—	—	—
$S_{31}(1620)$	**	1672	154	7	21	9	—	62_D	$25_S + 4_D$	—	—	—
$D_{33}(1700)$	*	1762	599	7	21	14	—	$74_S + 4_D$	8_S	—	—	—
$P_{31}(1910)$	****	1882	239	14	—	23	—	—	—	—	67	10_P
$P_{33}(1600)$	***	1706	430	14	—	12	—	68_P	—	—	20	—
$F_{35}(1905)$	***	1881	327	7	21	12	—	1_P	87_P	—	—	—
$F_{37}(1950)$	****	1945	300	14	—	38	—	18_F	—	—	—	44_F

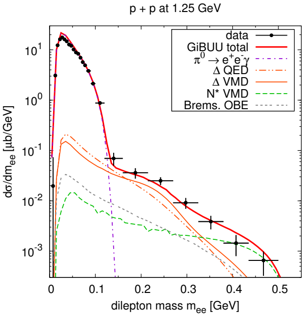
$$\Gamma_{R\to ab}(m) = \Gamma^0_{R\to ab}\frac{\rho_{ab}(m)}{\rho_{ab}(M^0)}$$

$$\rho_{ab}(m) = \int \mathrm{d}p_a^2\mathrm{d}p_b^2\mathcal{A}_a(p_a^2)\mathcal{A}_b(p_b^2)\frac{p_{ab}}{m}B^2_{L_{ab}}(p_{ab}R)\mathcal{F}^2_{ab}(m)$$

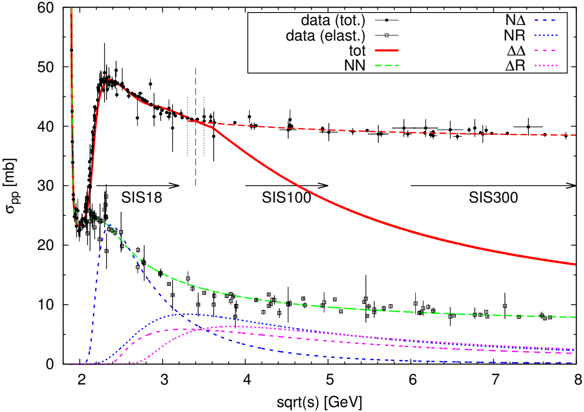
Delta

- $\Delta \to \rho N$ coupling can not be directly inferred from $\pi N \to 2\pi N$ data
- Δ is too light to decay into ρN (on the mass shell)
- but: off-shell Δ can decay into off-shell ρ
- this coupling can be important for dilepton spectra
- we introduce a p-wave decay with an (on-shell) BR of $5 \cdot 10^{-5}$
- $\Rightarrow$ consistent model with (implicit) sVMD FF for all baryons





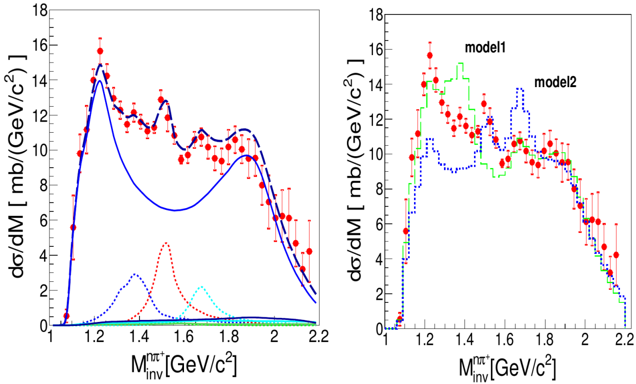
Resonances vs. Strings



- resonance model can saturate total cross section up to $\sqrt{s} \approx 3.4 GeV$
- switch from resonance descr. to string model at that energy
- but: resonance effects might still be important above

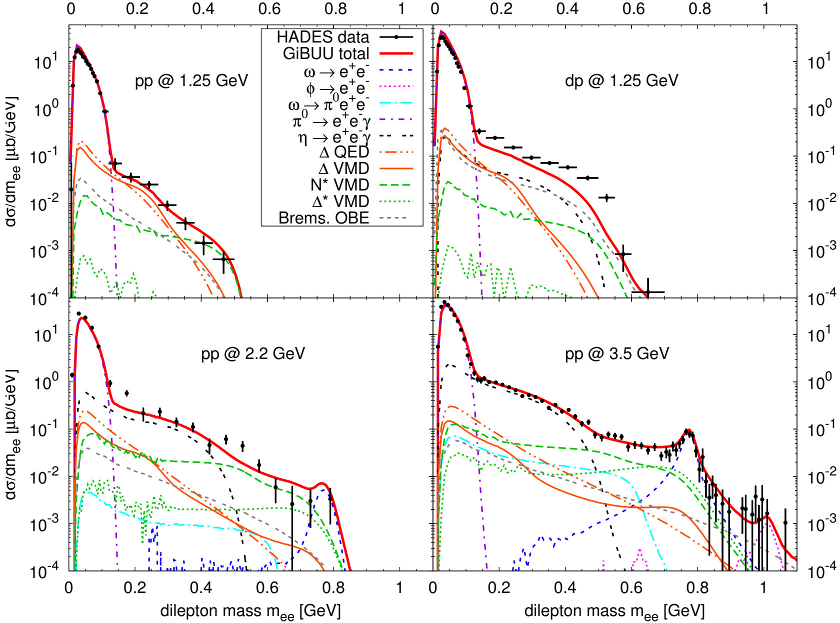
SIS18 is resonance land!

- highest HADES energy: pp at 3.5 GeV
- πN spectra show significant contributions of higher resonances (N^*, Δ^*)

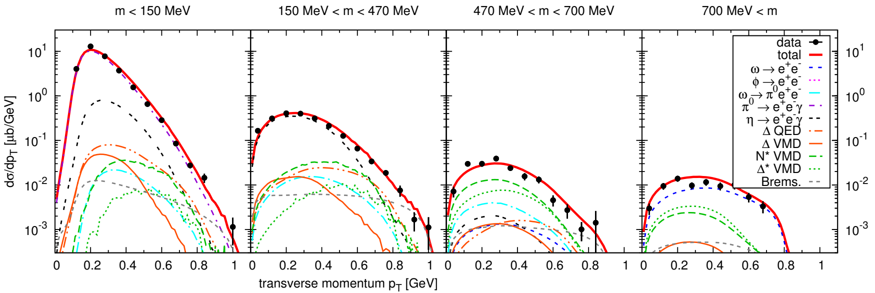


- arXiv:1403.3054
- model 1 = "GiBUU-like", model 2 = "UrQMD-like"

HADES: ELEMENTARY REACTIONS

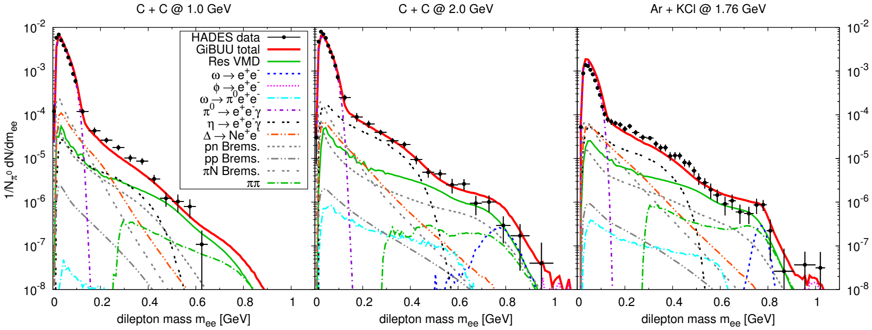


p_T spectra at 3.5 GeV



- VMD approach shifts p_T spectra to lower values
- only way to obtain decent agreement with data
- solid confirmation of both VMD approach and importance of N^* contributions

HADES: nucleus-nucleus collisions

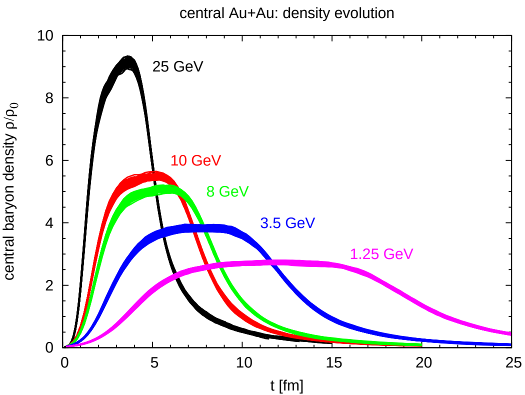


- pure on-shell transport
- effects like rescattering, absorption and production kinematics included
- no explicit in-medium spectral functions

lessons from HADES

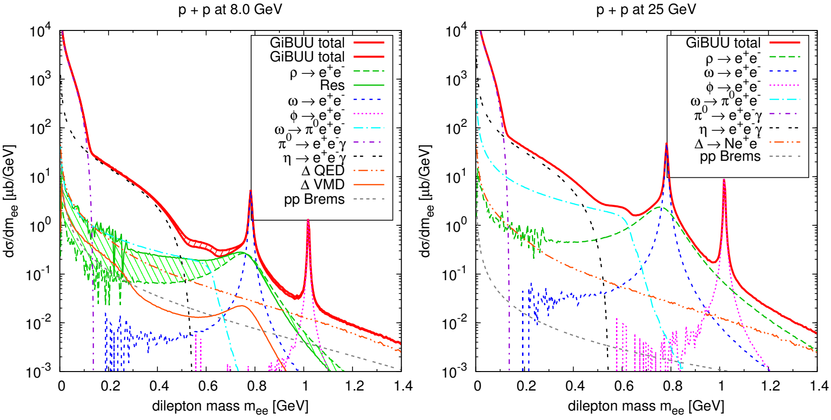
- baryons play an important role at low energies!
- already in vacuum!
- VMD seems to be a good assumption for all baryons
- on-shell transport can capture a good part of the relevant physics in medium-sized systems
- also for Au+Au? remains to be seen ...

MOVING TO CBM



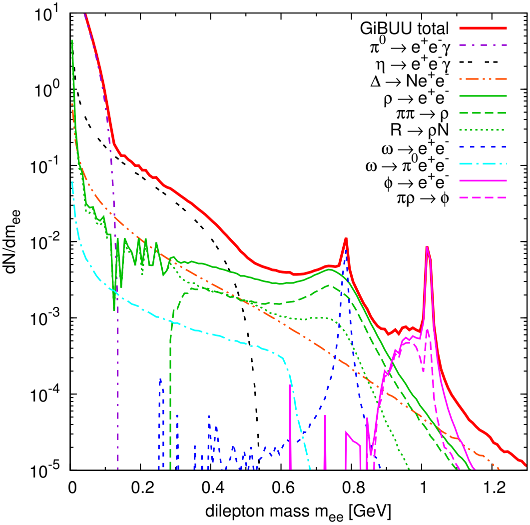
- density increases strongly
- but lifetime of dense phase decreases
- dileptons: vacuum should become simpler, but in-medium more interesting

pp at 8/25 GeV



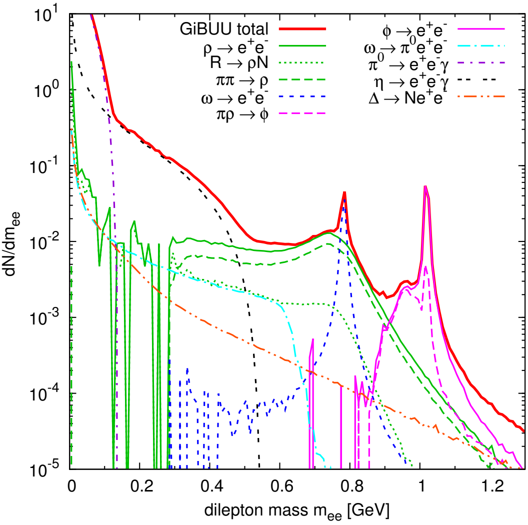
- at 8 GeV: some Res. effects in ρ production
- at higher energies probably negligible
- Δ: significant sensitivity to FF

Au+Au at 8 AGeV



- ρ mostly from $\pi\pi$
- minor resonance effects
- some nontrivial effect in the ϕ (to be checked!)

Au+Au at 25 AGeV



- somewhat similar to 8 GeV case
- again: just on-shell transport
- significant in-medium effects expected (see next talk)

Summary / Conclusions for CBM

- baryonic resonances should play a lesser role in vacuum (still significant at SIS100?)
- but: expected to be more important in medium
- on-shell transport probably not sufficient to describe dileptons
- consistent off-shell transport is very hard!
- coarse graining might be a good compromise (see next talk)
- ultimate goal: understand dilepton data in a wide energy range within one consistent framework
- CBM will provide crucial input
- we need open and transparent models for FAIR!