Dilepton Production in transport-based approaches

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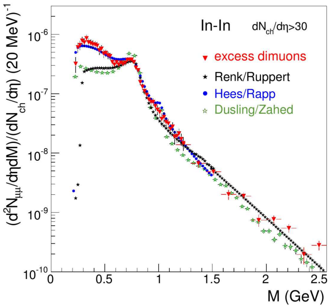
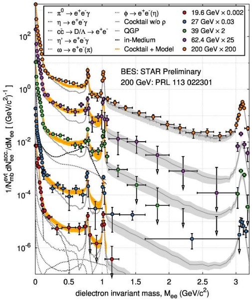
Outline

- Intro
  - dilepton physics
  - vector mesons in medium
- transport models
  - basic principles
  - assumptions & input
- two approaches to dilepton production:
  - 'pure' transport (GiBUU)
  - coarse graining (UrQMD + Rapp SF)
- comparison to data
  - HADES (pp and AA)
  - NA60

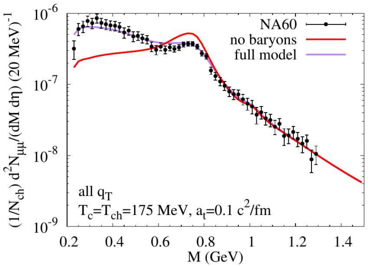
- lepton pairs (e^+e^-, $\mu^+\mu^-$) are an ideal probe to study phenomena at high densities and temp.
- in particular: modification of vector-meson spectral function in medium and chiral sym. restoration
- experiments: NA60, STAR/PHENIX, HADES, CBM

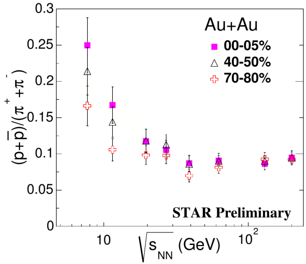




Vector Mesons in Medium

- NA60 showed clearly: ρ^0 spectral function substantially broadened in medium (but no mass shift)
- mainly driven by baryonic effects (collisions with nucleons, coulping to resonances)
- largest effects at low energies (DLS/HADES), but: also most challenging ('DLS puzzle')





The GiBUU model

- hadronic transport model (microscopic, non-equilibrium), based on the Boltzmann-Uehling-Uhlenbeck equation
- developed for 20+ years in Giessen (in the group of U. Mosel)
- current contributors: T. Gaitanos, K. Gallmeister, A. Larionov, J. Weil, U. Mosel
- unified framework for electroweak (γA, eA, νA) and hadronic (pA, πA, AA) nuclear reactions
- code available as open source (http://gibuu.hepforge.org)
- review paper: O. Buss et al., Phys. Rep. 512 (2012)

GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project

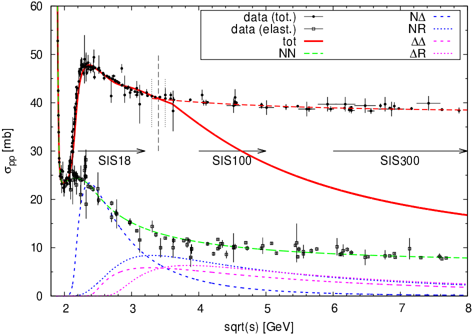
The BUU equation

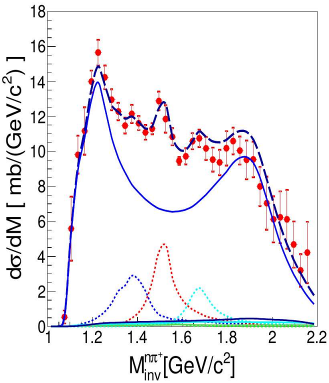
- BUU equ.: space-time evolution of phase-space density F (via gradient expansion from Kadanoff-Baym)

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

- degrees of freedom: hadrons (61 baryons and 22 mesons included)
- Hamiltonian H:
  - hadronic mean fields (Skyrme or RMF), Coulomb, ...
- collision term $C(x,p)$: decays and collisions
  - low energy: resonance-model approach
  - high energy: string fragment. (Pythia)
- solve numerically via test-particle method:
  $F = \sum_i \delta(\vec{r}-\vec{r}_i)\delta(p-p_i)$

Resonances vs. Strings





- resonance model can saturate total cross section up to $\sqrt{s} \approx 3.4 GeV$ (then: switch to string model)
- HADES πN spectra show clear contributions of higher resonances (N^*, Δ^*) at $\sqrt{s} = 3.2\,\mathrm{GeV}$ (arXiv:1403.3054)

Resonance Model

- at SIS energies: particle production dominated by resonance formation
- GiBUU res. model is based on Manley/Saleski PWA (Phys. Rev. D 45, 1992; including $\pi N \to \pi N$ / $2\pi N$ data)
- 13 N^*/Δ^* states excited in NN collisions

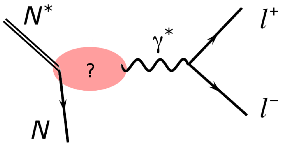
		M_0	Γ_0	$\lvert\mathcal{M}^2\rvert/16\pi$ [mb GeV^2]		branching ratio in %						
	rating	[MeV]	[MeV]	NR	ΔR	πN	ηN	$\pi\Delta$	ρN	σN	$\pi N^*(1440)$	$\sigma\Delta$
$P_{11}(1440)$	****	1462	391	70	—	69	—	22_P	—	9	—	—
$S_{11}(1535)$	***	1534	151	8	60	51	43	—	$2_S + 1_D$	1	2	—
$S_{11}(1650)$	****	1659	173	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

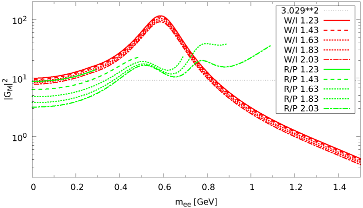
$R \to e^+e^-N$: the 'traditional' treatment

- $R = \Delta, N^*, \Delta^*$
- 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.):

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

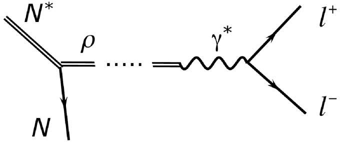
- problem: form factor basically unknown in time-like region, often neglected (avail. models: Wan/Iachello, Ramalho/Pena)





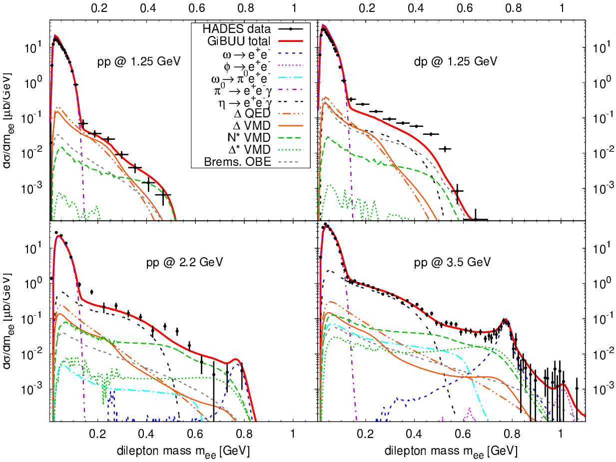
Our Approach: Vector-Meson Dominance

- assumption: baryons couple to em. sector only through ρ (strict VMD)



- in transport model: two-step treatment (factorization), intermediate ρ can be rescattered
- $\Delta(1232)$: introduce ρN coupling with on-shell BR of $5 \cdot 10^{-5}$

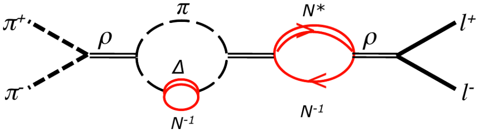
Elementary Results



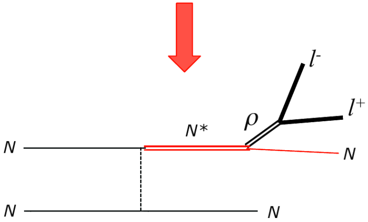
- excellent agreement with all pp data
- significant res. contributions (via VMD)
- dp underestimated (despite inclusion of OBE bremsstrahlung by Shyam et al.)
- further isospin-enhancement of ρ in np required?

SPS/RHIC vs SIS energies

SPS, RHIC, LHC

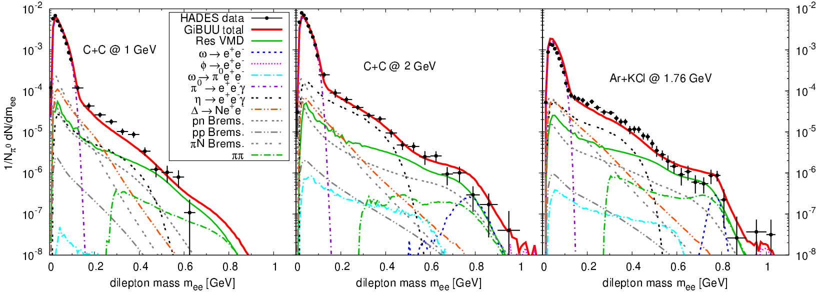


SIS



'in-medium' physics at SPS connected to 'vacuum' physics at SIS!

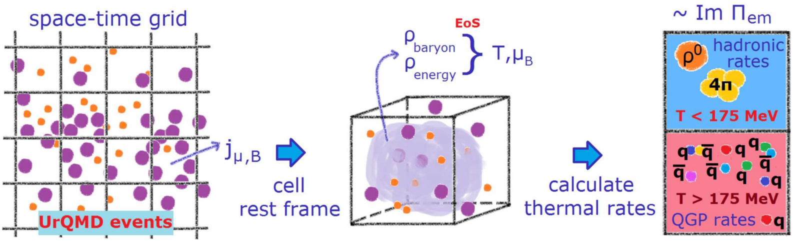
Nucleus-Nucleus Results



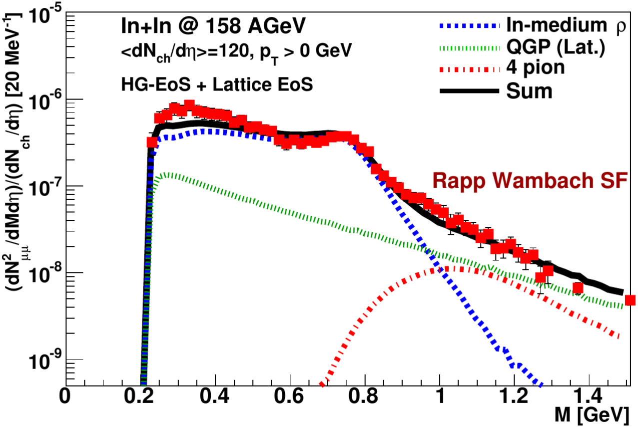
- on-shell transport (with vacuum spectral functions) already yields rather good results
- further improvements might be obtained by including explicit in-med. spectral functions (via 'coarse graining' or 'off-shell transport')
- or: better input? (form factors, rho-baryon coupling)

"Coarse Graining"

- PhD project of Stephan Endres
- put UrQMD simulation onto space-time grid
- for each cell, determine baryon and energy density
- use equation of state to calculate local temperature and baryo-chemical potential
- calculate thermal dilepton rates using Rapp-Wambach spectral function (Rapp 1997, NPA 617)

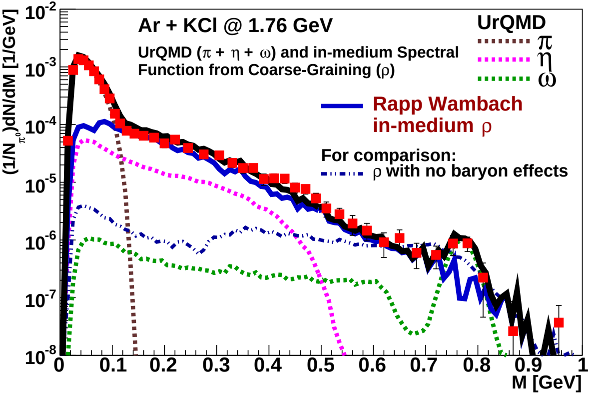


Results: NA60



- good agreement with NA60, reproducing Rapp/Hees results
- benchmark/proof of principle
- plus: better fireball description (non-homogeneous)

Results: Ar+KCl at 1.76 GeV (HADES)



- very good agreement (best description of this data so far)
- dominant ρ in-medium contribution
- baryonic effects are crucial

Summary/Conclusions

- pure transport simulations get close to describing HADES dilepton data, when given proper input (ρ-R couplings!)
- coarsed-grained transport gives almost perfect description using Rapp spectral function
- open questions:
  - understand differences in detail
  - is Rapp SF. in agreement with HADES pp data?
- future work:
  - HADES Au+Au & pion beam
  - coarse-graining results for RHIC BES

The End

Thanks for your attention!