

DILEPTON PRODUCTION IN TRANSPORT-BASED APPROACHES

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Hot Quarks 2014



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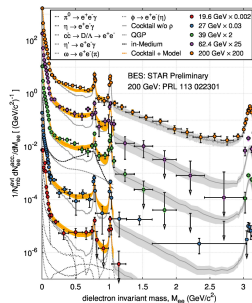
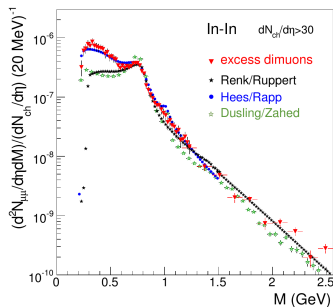
HELMHOLTZ
| **GEMEINSCHAFT**

HIC | **FAIR**
for
Helmholtz International Center

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

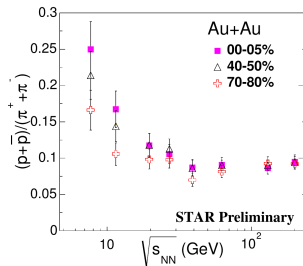
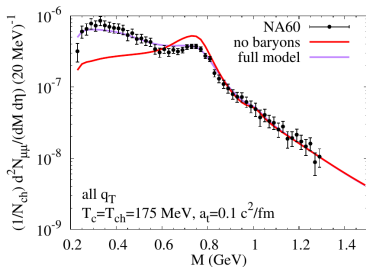
INTRO: DILEPTONS

- 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: HADES, CBM, NA60, STAR/PHENIX, ALICE



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, coupling to resonances)
- largest effects at low energies (DLS/HADES), but: also most challenging ('DLS puzzle')



- hadronic transport model (microscopic, non-equilibrium)
- based on the Boltzmann-Uehling-Uhlenbeck (BUU) equation
- BUU equ.: space-time evolution of phase-space density F

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

- degrees of freedom: hadrons
(61 baryons and 22 mesons included)
- Hamiltonian H : contains hadronic mean fields etc
- collision term C : decays and collisions
 - low energy: res.-model, high energy: string fragment.
- solve numerically via test-particle method:
$$F = \sum_i \delta(\vec{r} - \vec{r}_i) \delta(p - p_i)$$
- code available as open source (<http://gibuu.hepforge.org>)
- review paper: O. Buss et al., Phys. Rep. 512 (2012)

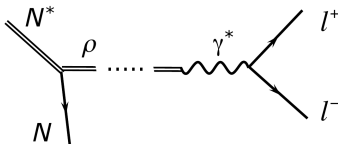
RESONANCE MODEL

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

	rating	M_0 [MeV]	Γ_0 [MeV]	$ \mathcal{M}^2 /16\pi$ [mb GeV ²]		branching ratio in %						
				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

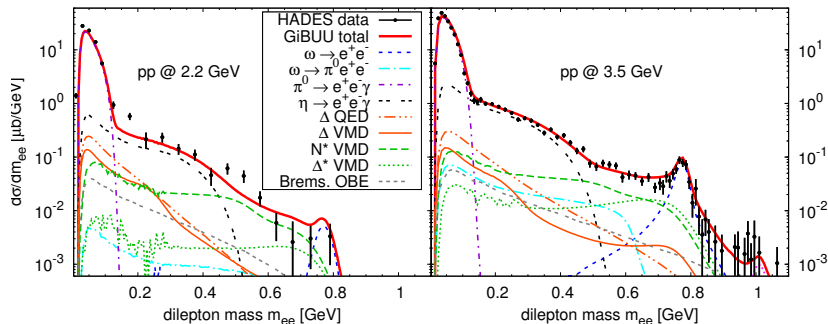
$R \rightarrow e^+e^-N$ DALITZ DECAYS

- $R = \Delta, N^*, \Delta^*$ (baryonic resonances)
- photon couplings ($R \rightarrow \gamma N$) known from photoproduction experiments ($\gamma N \rightarrow X$)
- can be extended to time-like region ($R \rightarrow \gamma^* N$) via em. transition form factor (Krivoruchenko et al.)
- our assumption: strict VMD (baryons couple to em. sector only through ρ)



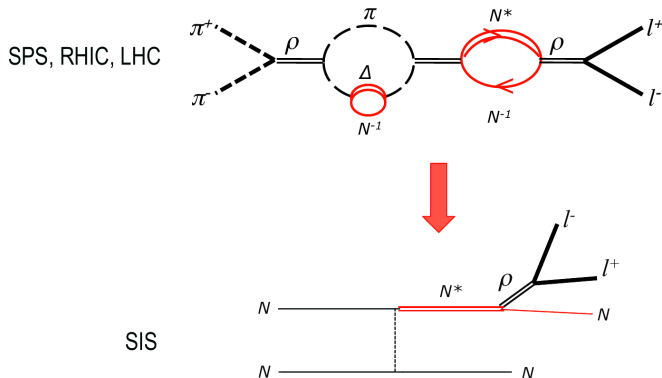
- in transport model: two-step treatment (factorization), intermediate ρ can be rescattered
- $\Delta(1232)$: introduce ρN coupling with on-shell BR of $5 \cdot 10^{-5}$

HADES: PP RESULTS



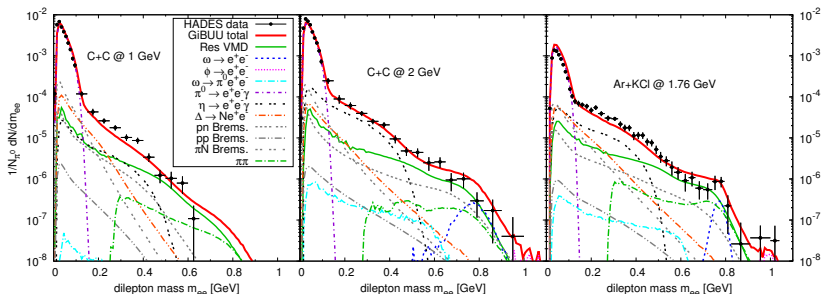
- good agreement with elementary pp data
- significant contributions of baryonic resonances (N^* , Δ^*) via VMD-based Dalitz decays
- Δ : two treatments shown (VMD vs. QED)

SPS/RHIC vs SIS ENERGIES



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

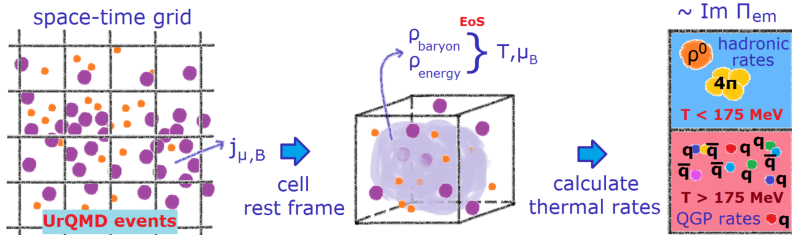
HADES: NUCLEUS-NUCLEUS RESULTS



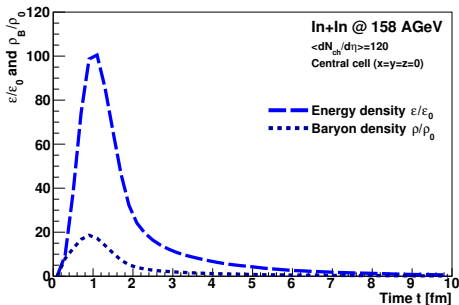
- on-shell transport (with vacuum spectral functions) already yields rather good results
- further improvements might be obtained by including explicit in-med. spectral functions (via 'coarse graining' or 'off-shell transport')
- or: better input? (form factors, rho-baryon coupling)

“COARSE GRAINING”

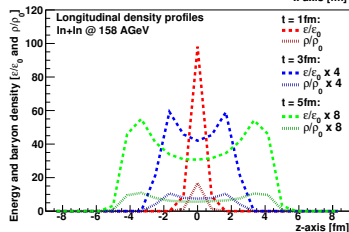
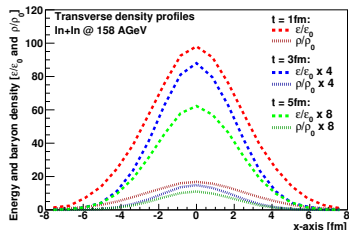
- PhD project of Stephan Endres
- put UrQMD simulation onto space-time grid
- for each cell, determine baryon and energy density
- use equation of state to calculate local temperature and baryo-chemical potential
- calculate thermal dilepton rates using Rapp-Wambach spectral function (Rapp 1997, NPA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



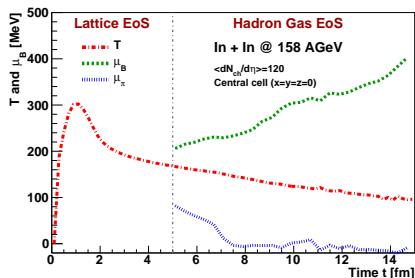
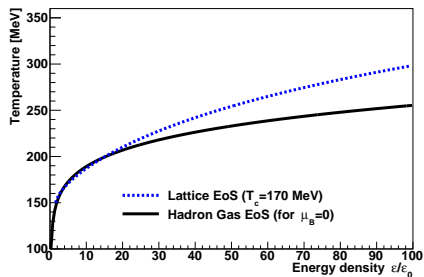
TIME EVOLUTION & DENSITY PROFILES (AT SPS)



- highest densities and temperatures reached at 1.2 fm ($100\epsilon_0$, $20\rho_0$, $T = 300$ MeV)
- transverse shapes very similar at all times (scaled!)



EQUATION OF STATE & TEMP. EVOLUTION



- below $T = 170$ MeV: hadron-gas EOS (Zschesche et al)
- above $T = 170$ MeV: lattice EOS (He/Fries/Rapp)
- smooth transition in temperature between lattice and HG EOS at $t \approx 5$ fm

- thermal equilibrium rates via em. current correlator:

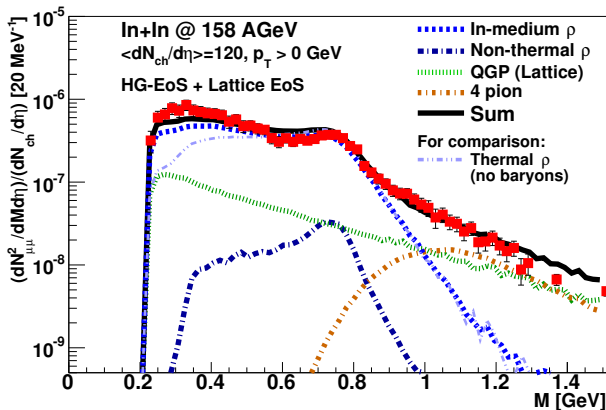
$$\frac{d^8 N_{II}}{d^4 x d^4 p} = -\frac{\alpha^2}{\pi^3} \frac{L(M^2)}{M^2} f_B(q_0; T) \text{Im} \Pi_{em}(M, q; T, \mu)$$

- hadronic phase: in-medium ρ propagator (Rapp et al.):

$$D_\rho = \frac{1}{M^2 - m_0^2 - \Sigma_{\rho\pi\pi} - \Sigma_{\rho M} - \Sigma_{\rho B}}$$

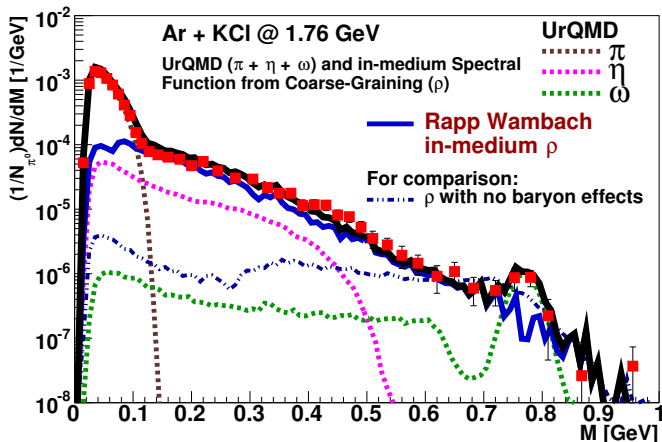
- QGP emission via $q\bar{q}$ annihilation from lattice QCD according to Ding, Francis et al., PRD83 (2011)

NA60 $\mu^+\mu^-$ SPECTRUM



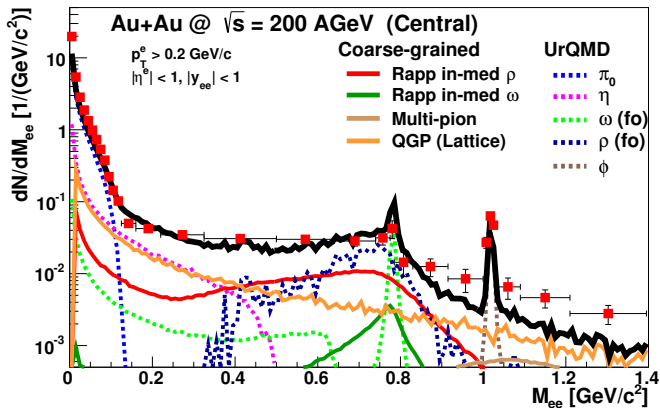
- good agreement with NA60 data, essentially reproducing earlier results by Rapp/Hees
- benchmark/proof of principle
- plus: improved fireball description

HADES: $AR+KCL$ AT 1.76 GeV



- very good agreement
- dominant ρ in-medium contribution
- baryonic effects are crucial

STAR: AuAu AT 200 AGeV (PRELIMINARY)



- IMR: underestimation due to missing $c\bar{c}$
- LMR: good agreement with data

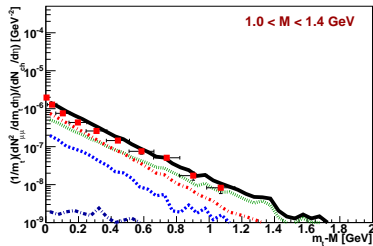
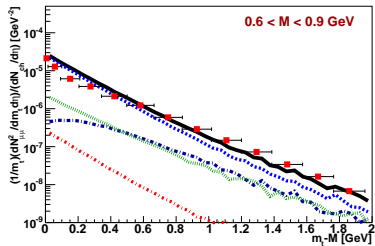
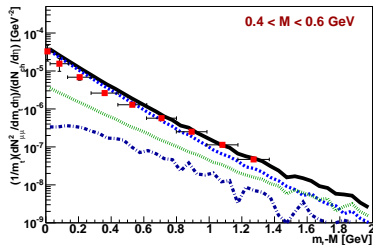
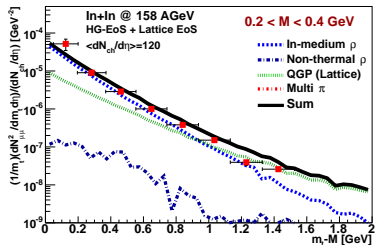
- pure transport simulations get very close to describing HADES data, when given proper input (ρ -R couplings!)
- coarse-grained transport (with Rapp spectral function) shows promising results from SIS over SPS to RHIC energies
- open questions:
 - understand differences at SIS in detail
 - is Rapp SF in agreement with HADES pp data?
- future work:
 - RHIC beam-energy scan
 - HADES Au+Au & pion beam
 - CBM at FAIR
 - extension to higher energies: use hybrid model for evolution

The End

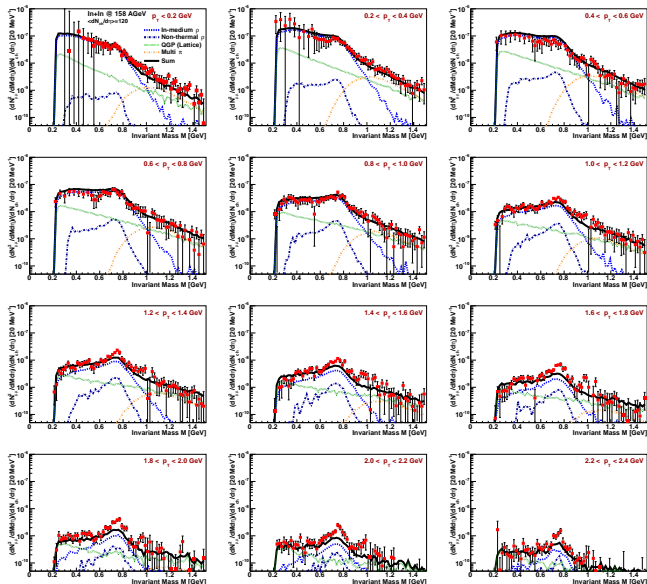
Thanks for your attention!

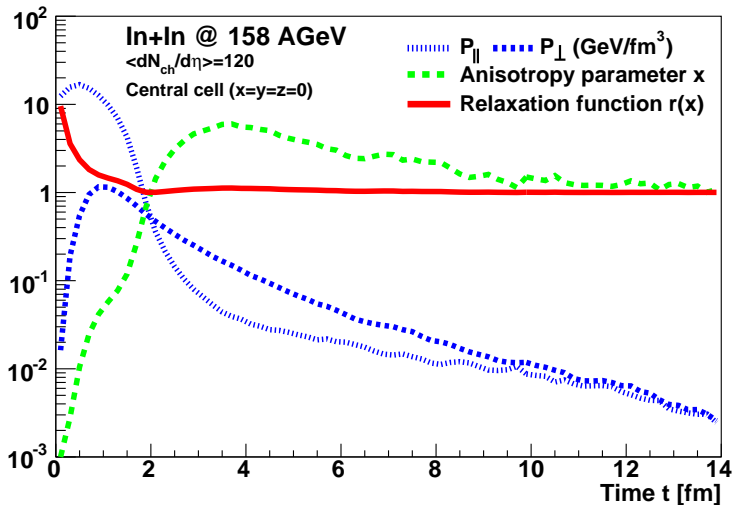
Backup Slides

NA60: m_T SPECTRA

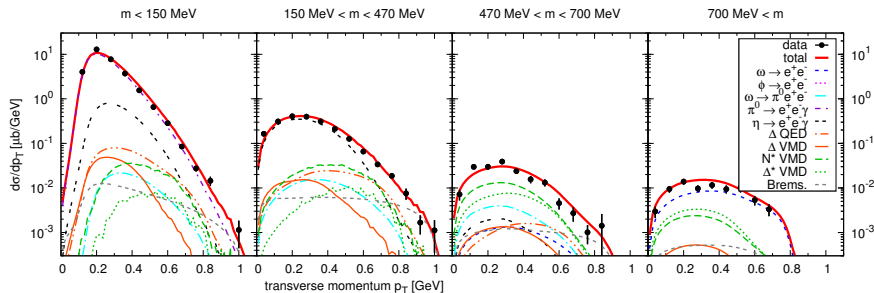


NA60: MASS SPECTRA IN PT SLICES





HADES 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