Dilepton Production in transport-based approaches

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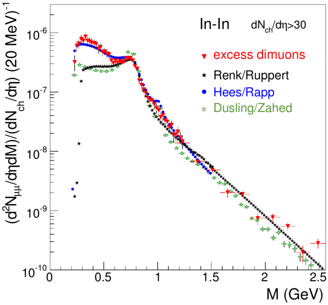
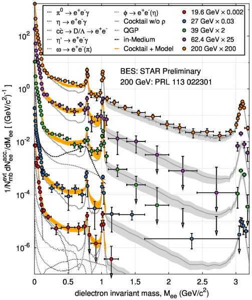
Outline

- 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

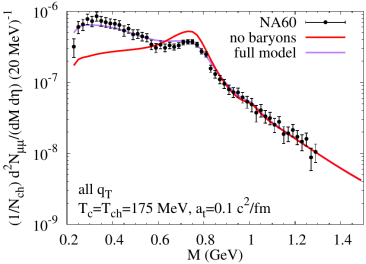
- lepton pairs (e^+e^-, $\mu^+\mu^-$) are an ideal probe to study phenomena at high densities and temp.
- in particular: modification of vector-meson spectral function in medium and chiral sym. restoration
- experiments: HADES, CBM, NA60, STAR/PHENIX, ALICE

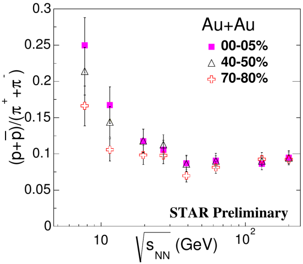




Vector Mesons in Medium

- NA60 showed clearly: ρ^0 spectral function substantially broadened in medium (but no mass shift)
- mainly driven by baryonic effects (collisions with nucleons, 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 (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)

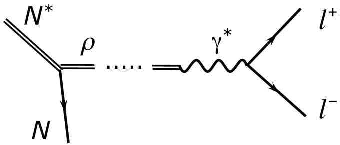
Resonance Model

- 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

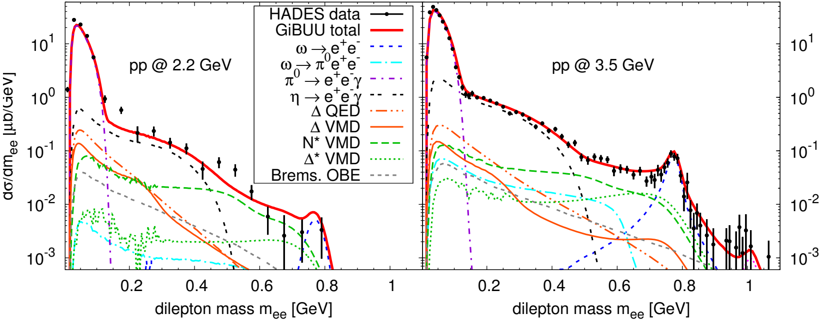
		M_0	Γ_0	$\lvert\mathcal{M}^2\rvert/16\pi$ [mb GeV^2]		branching ratio in %						
	rating	[MeV]	[MeV]	NR	ΔR	πN	ηN	$\pi\Delta$	ρN	σN	$\pi N^*(1440)$	$\sigma\Delta$
$P_{11}(1440)$	****	1462	391	70	—	69	—	22_P	—	9	—	—
$S_{11}(1535)$	***	1534	151	8	60	51	43	—	$2_S + 1_D$	1	2	—
$S_{11}(1650)$	****	1659	173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

$R \to e^+e^-N$ Dalitz decays

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

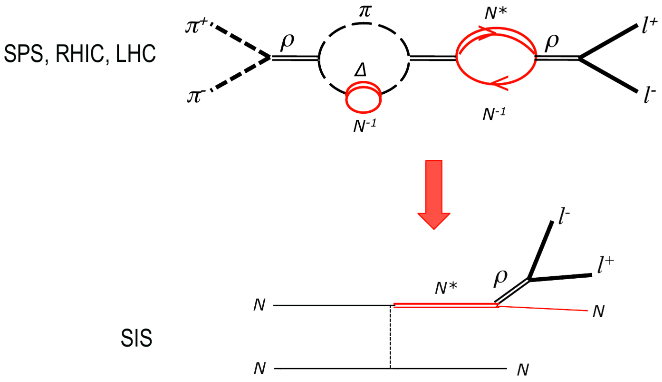


- in transport model: two-step treatment (factorization), intermediate ρ can be rescattered
- $\Delta(1232)$: introduce ρN coupling with on-shell BR of $5 \cdot 10^{-5}$



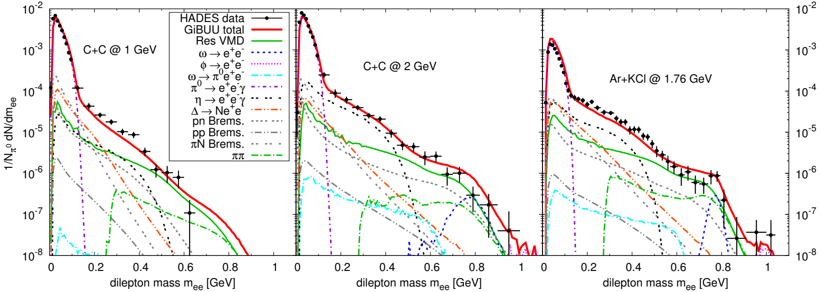
- good agreement with elementary pp data
- significant contributions of baryonic resonances (N^*, Δ^*) via VMD-based Dalitz decays
- Δ: two treatments shown (VMD vs. QED)

SPS/RHIC vs SIS energies



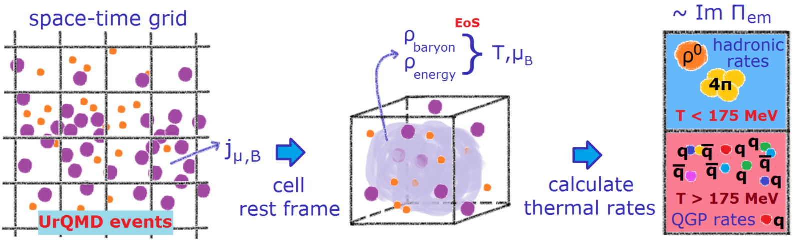
'in-medium' physics at SPS connected to 'vacuum' physics at SIS!

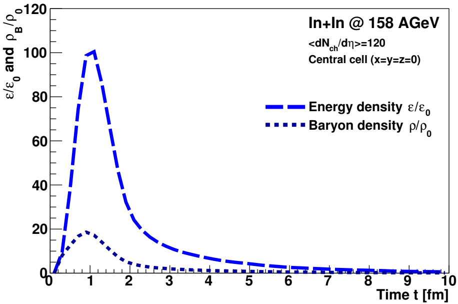
HADES: Nucleus-Nucleus Results

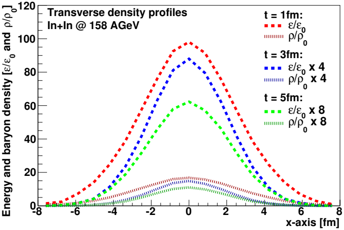


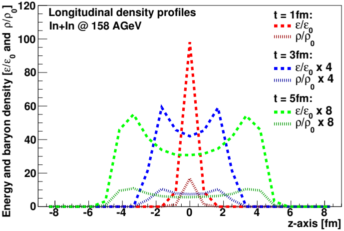
- on-shell transport (with vacuum spectral functions) already yields rather good results
- further improvements might be obtained by including explicit in-med. spectral functions (via 'coarse graining' or 'off-shell transport')
- or: better input? (form factors, rho-baryon coupling)

- 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)



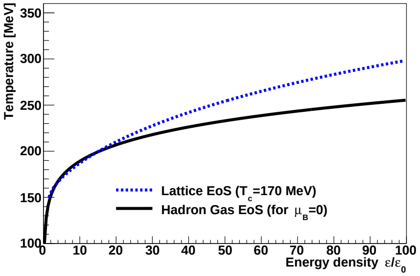


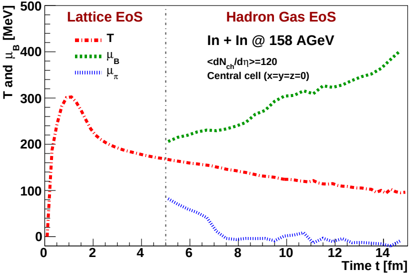




- highest densities and temperatures reached at 1.2 fm ($100\epsilon_0$, $20\rho_0$, $T = 300\,\mathrm{MeV}$)
- transverse shapes very similar at all times (scaled!)

Equation Of State & temp. evolution





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

- thermal equilibrium rates via em. current correlator:

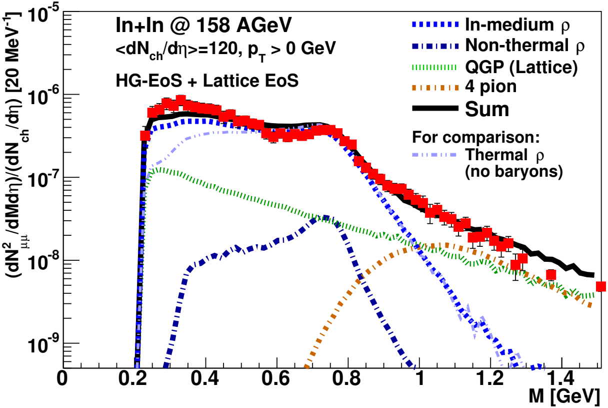
$$\frac{d^8 N_{ll}}{d^4 x d^4 p} = -\frac{\alpha^2}{\pi^3} \frac{L(M^2)}{M^2} f_B(q_0; T) Im\Pi_{em}(M, q; T, \mu)$$

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

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

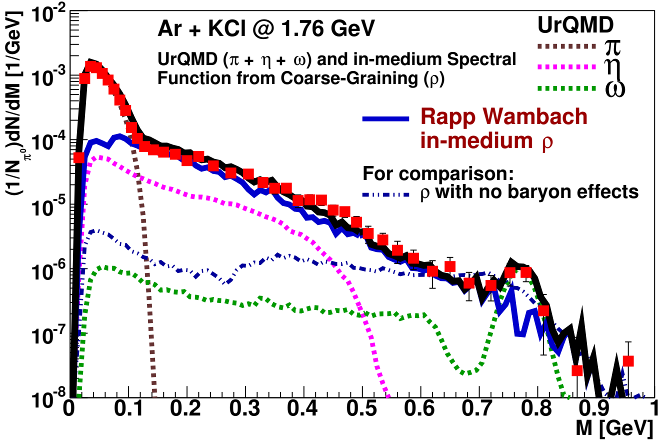
- QGP emission via $q\bar{q}$ annihilation from lattice QCD according to Ding, Francis et al., PRD83 (2011)

NA60 $\mu^+\mu^-$ spectrum



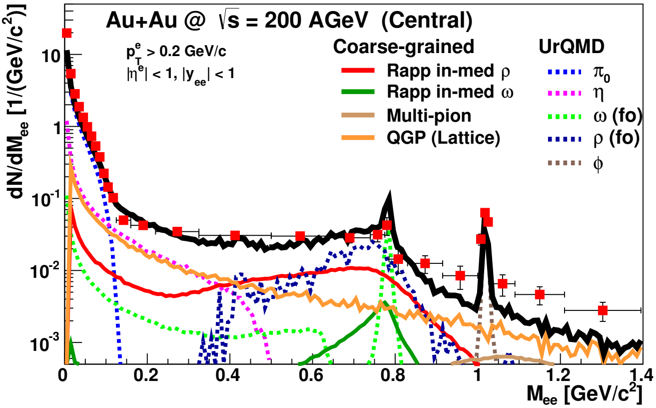
- good agreement with NA60 data, essentially reproducing earlier results by Rapp/Hees
- benchmark/proof of principle
- plus: improved fireball description

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

Summary/Conclusions

- 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!