Dilepton and pion production at SIS energies

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Intro & Motivation

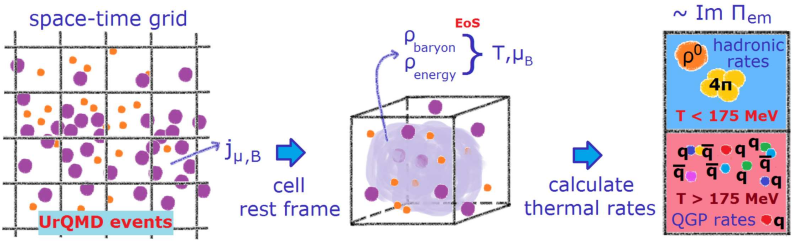
- large amounts of new dilepton data measured by HADES are becoming available
- will help to improve our understanding of vector mesons in medium
- proper models are needed to understand & interpret those data
- we rely on transport-based approaches:
  - "pure" microscopic transport
  - "coarse-grained" transport
- in order to understand dilepton spectra we also need to understand pion production:
  - normalization of dilepton spectra to N_π
  - both are dominated by resonance dynamics at SIS (few GeV)

Coarse Graining

(with S. Endres, H. van Hees, M. Bleicher)

"Coarse Graining"

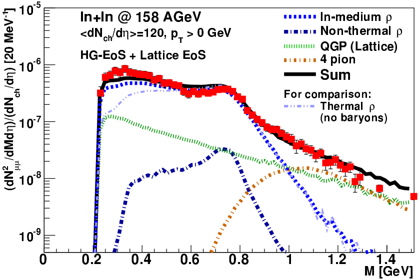
- PhD project of S. Endres
- put UrQMD simulation onto space-time grid
- for each cell, determine baryon and energy density
- use equation of state to calculate local temperature and baryo-chemical potential
- calculate thermal dilepton rates using Rapp-Wambach spectral function (Rapp 1997, NPA 617)

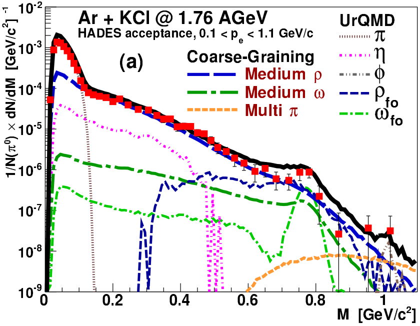


Results: NA60 & HADES

- NA60: benchmark result, essentially reproducing earlier calc. by Rapp/Hees (in a fireball model)
- Endres, Hees, Weil, Bleicher, arXiv:1412.1965

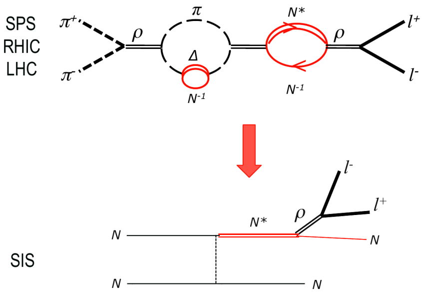
- HADES: genuinely new result (to be published soon)
- best description of ArKCl dilepton spectrum yet





CG: Conclusions

- coarse-graining provides important connection between SPS and SIS energies
- data in both energy regimes seem to be compatible with in-medium SF by Rapp et al.
- ρ meson SF is modified in medium mostly due to coupling to baryon resonances (N^*)



Open Questions:

- what are the most significant contributions to the in-medium ρ SF at SIS energies (which resonances, Bremsstrahlung?)
- can we understand this physics in a microscopic description?
- how to make a connection to 'elementary-beam' measurements (pp, pA, πp, πA)

Pure Transport

(with the GiBUU model)

The GiBUU transport model

- microscopic, non-equilibrium description of nuclear reactions
- BUU equ.: space-time evolution of phase-space density F (from gradient expansion of Kadanoff-Baym eq.)

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

- Hamiltonian H:
  - hadronic mean fields, Coulomb
- collision term $C(x,p)$:
  - decays and scattering processes (2- and 3-body)
  - low energy: resonance model, high energy: string fragment.
- model includes 61 baryons and 22 mesons
- http://gibuu.hepforge.org, O. Buss et al., Phys. Rep. 512 (2012)

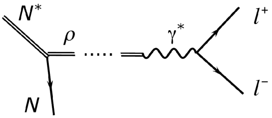
GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

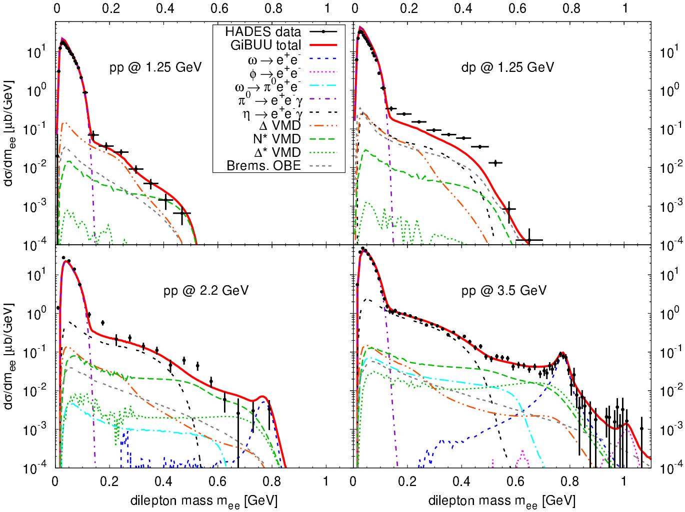
Resonance Model

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

- GiBUU res. model is based on Manley/Saleski PWA (Phys. Rev. D 45, 1992; including $\pi N \to \pi N$ / $2\pi N$ data)
- assumption: strict VMD (baryons couple to em. sector only through ρ)

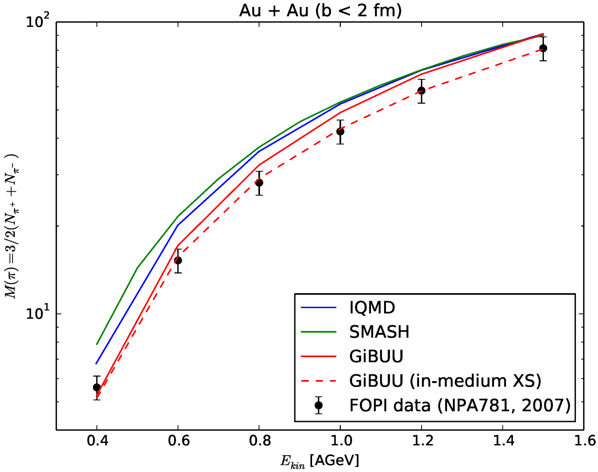


HADES: pp



- ρ shape already nontrivial in pp collisions due to production mechanism via resonances

Pion production in central Au+Au



- models typically overestimate data by 10-20%
- can be cured by introducing density-dependent cross sections

IN-MEDIUM CROSS SECTION FOR Δ PRODUCTION

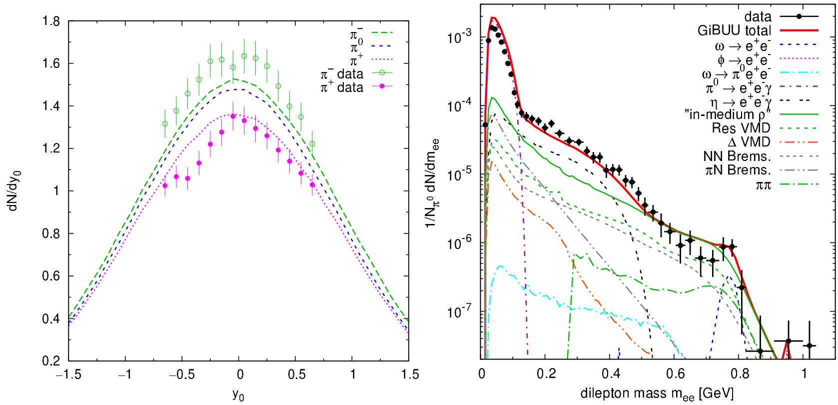
- prescription according to Song/Ko (arXiv:1403.7363):

$$\sigma_{NN\to N\Delta}(\rho) = \sigma_{NN\to N\Delta}(0) \cdot \exp(-A\rho/\rho_0)$$
$$\text{with } A = 1.2$$

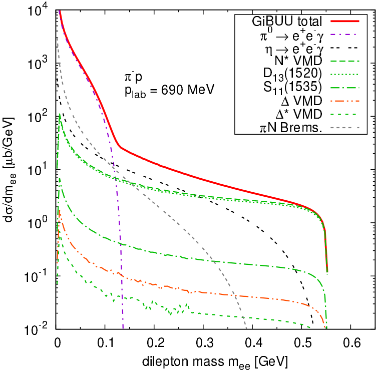
- cross section reduced to 30% at ρ_0 and to 9% at $2\rho_0$

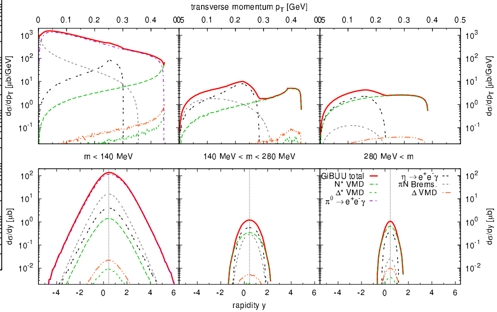
- in-medium modification applied only to $NN \to N\Delta$
- other sources of pions not modified:
  - $NN \to NN\pi$ background
  - $NN \to \Delta\Delta$
  - $NN \to NN^*$

ArKCl@1.76: pions and dileptons



- reasonable agreement with charged-pion yields
- dilepton spectrum described within 30%





- GiBUU prediction, waiting for data
- pion-beam data will help to constrain resonance contributions and form factors

Summary / Conclusions / Outlook

- we have studied dilepton production at SIS in two approaches: 'pure' and 'coarse-grained' transport
- both agree qualitatively on the importance of baryonic Dalitz-like contributions to the dilepton spectrum
- further constraints from pion-beam measurements will improve our quantitative understanding of resonance contributions
- check how models compare to AuAu data