Electromagnetic Probes in Heavy-Ion Collisions

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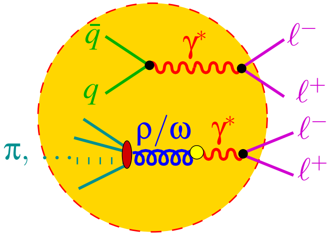
Outline

Dileptons and in-medium em. current correlation function



- Dilepton emission rate [McLerran, Toimela 85]

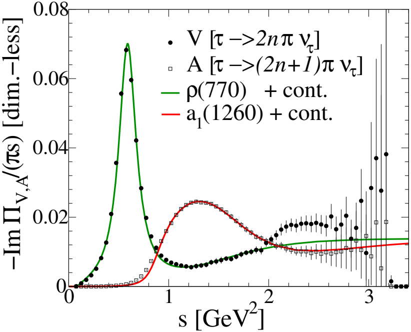
$$\frac{\mathrm{d}N_{e^+e^-}}{\mathrm{d}^4x\mathrm{d}^4q} = -g^{\mu\nu}\frac{\alpha_{\mathrm{em}}^2}{3q^2\pi^3}\,\mathrm{Im}\,\Pi_{\mu\nu}^{(\mathrm{em})}(q)\Big|_{q^2=M_{e^+e^-}^2} f_B(q_0)$$

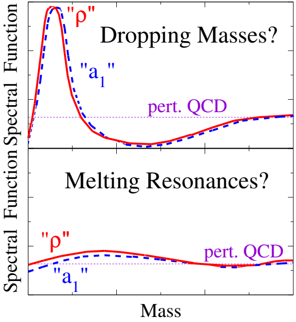
$$\Pi_{\mu\nu}^{(\mathrm{em})}(q) = \int \mathrm{d}^4x \exp(\mathrm{i}q\cdot x)\Theta(x_0)\left\langle\left[j_\mu^{(\mathrm{em})}(x), j_\nu^{(\mathrm{em})}(0)\right]\right\rangle_T$$

- $\ell^+\ell^-$ spectra $\Leftrightarrow$ in-medium em. current-current correlator
- Vector dominance $\Rightarrow$ in-medium modifications of vector mesons!

Chiral Symmetry Restoration

- light-quark sector of QCD: chiral symmetry
  - spontaneously broken in vacuum ($\langle \bar{q}q \rangle \neq 0$)
  - high temperature/density: restoration of chiral symmetry
  - Lattice QCD: $T_c^{\chi} \simeq T_c^{\mathrm{deconf}}$



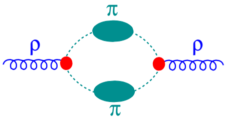


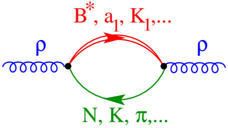
- Mechanism of chiral restoration?
  - "dropping masses": $m_{\mathrm{had}} \propto \langle \bar{\psi}\psi \rangle$
  - "melting resonances": broadening of spectra through medium effects

Hadronic many-body theory

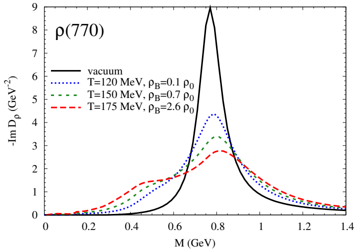
- pion-cloud modifications and baryonic/mesonic excitations

  [Chanfray et al, Herrmann et al, Ko et al, Rapp et al, Klingl et al, Post et al, Friman et al, . . .]

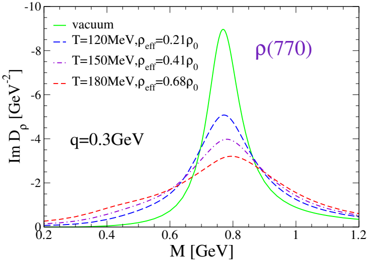




SPS



RHIC

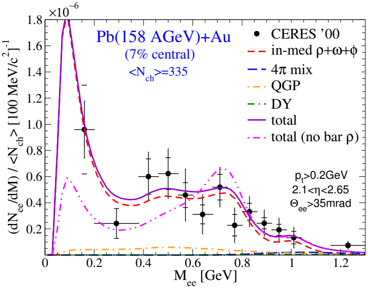


- substantial broadening of vector mesons with little mass shift!
  - baryon effects prevalent ($\rho_B + \rho_{\bar{B}}$, not $\rho_B - \rho_{\bar{B}}$, relevant!)
  - different approaches consistent if constrained by data (γN, γA, $\pi N \to \rho N$)

CERES vs. Hadronic many-body theory

- Dilepton emission from thermal source
- thermal fireball evolution (isentropic QGP/MIX + hadron gas)

$$\frac{\mathrm{d}N_{\ell\ell}^{\text{therm}}}{\mathrm{d}M} \propto -\int_{\text{FB}} \mathrm{d}^4x \int \frac{\mathrm{d}^3 q}{M q_0} \,\mathrm{Im}\, \Pi^{(\text{em})}(q_0, \vec{q}) f_B(q_0) \text{Acc}$$

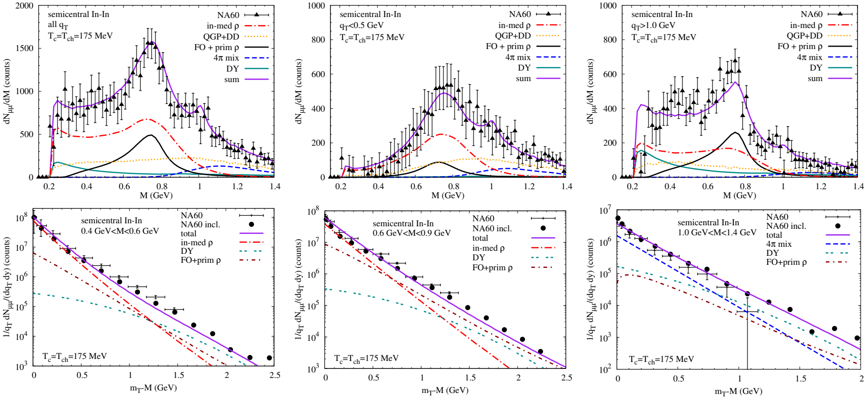


[HvH, R. Rapp 07]

- baryon effects essential!
  - many-body effects ⇔ very low-mass excess

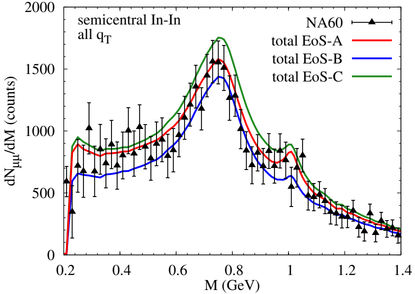
NA60 vs. Hadronic many-body theory

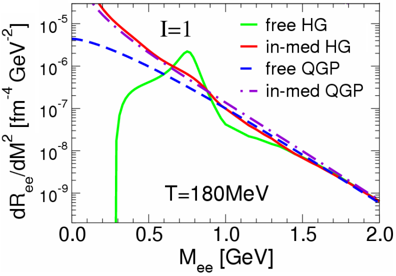
- ρ, ω, ϕ multi-π, QGP, freeze-out+primordial ρ, Drell-Yan



- M spectra [HvH, Rapp 07]
  - consistent with predicted broadening of ρ meson
  - $M <$ 1GeV: thermal ρ; $M > 1$ GeV: thermal multi-pion processes
- m_t spectra
  - $q_t < 1$ GeV: thermal radiation
  - $q_t > 1$ GeV: freeze-out + hard primordial ρ, Drell-Yan

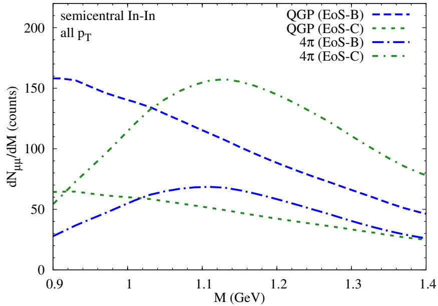
Critical temperature and freeze-out

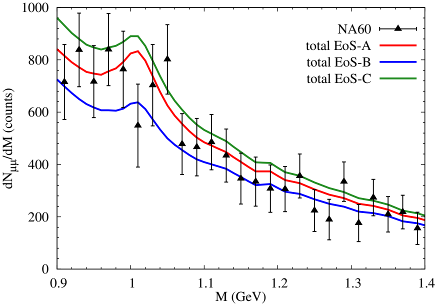




- EoS-A: $T_c = T_{\text{chem}} = 175$ MeV; EoS-B: $T_c = T_{\text{chem}} = 160$ MeV
  EoS-C: $T_c = 190$ MeV, $T_{\text{chem}} = 160$ MeV
  - norm depends on t_{fireball} (kept fixed here)!
  - description of spectra comparable
  - reason for insensitivity to EoS and hadro-chemistry [HvH, Rapp 07]:
  - hadronic and partonic radiation "dual" for $T \sim T_c$
    (pQCD: $\Pi_V \equiv \Pi_A \Rightarrow$ compatible with chiral symmetry restoration!)

Intermediate mass region – QGP vs. hadron gas

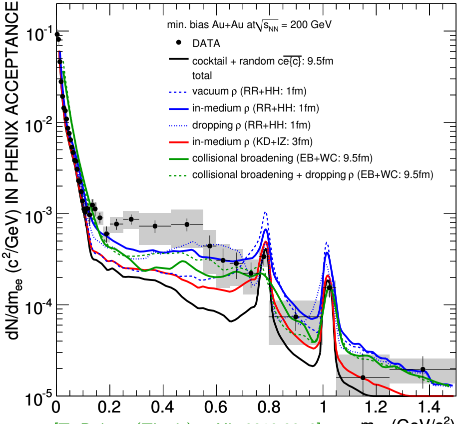




[HvH, Rapp 07]

- EoS-B: $T_c = T_{\text{chem}} = 160$ MeV (large QGP part)
  EoS-C: $T_c = 190$ MeV, $T_{\text{chem}} = 160$ MeV (small QGP part)
- volume $\leftrightarrow$ T: emission dominated by temperatures around T_c (QGP vs. high-density hadronic phase)
- description of spectra comparable for different EoS

PHENIX e^+e^--mass spectrum



[T. Dahms (Thesis), arXiv:0810.3040]

- RR: hadronic many-body theory [Rapp 01, 02] (for $N_{\text{part}} = 125$)
- KD+IZ: chiral reduction formalism [Dusling, Zahed 07]
- EB+WC: Transport model (HSD) [E. L. Bratkovskaya, W. Cassing, O. Linnyk 08]
- LMR enhancement cannot be described!

Conclusions and Outlook

- hadronic many-body theory
  - broadening, small mass shifts of spectra (baryon effects prevalent)
  - hadron-parton duality of dilepton rates (QGP portion depends on T_c)
- Heavy-ion collisions
  - CERES, NA60: Hadronic many-body theory robust due to duality involved mix of contributions at high q_T
  - PHENIX: Low-mass enhancement can not be described!
- Not covered in this talk: Thermal Photons
  - Same em. correlator as for dileptons!
  - Hadronic many body theory: improvement in description of WA98 data [Liu, Rapp 06]
- Connection between chiral symmetry restoration and dilepton data
  - hadronic chiral model at finite $T \Rightarrow \Pi_V$ and Π_A
  - confront Π_V with dilepton data
  - check moments of $\Pi_V - \Pi_A$ with lQCD via Weinberg sum rules