Dileptons at LHC

Hendrik van Hees

Texas A&M University

June 2, 2007

with Ralf Rapp

Outline

Electromagnetic probes in heavy-ion collisions

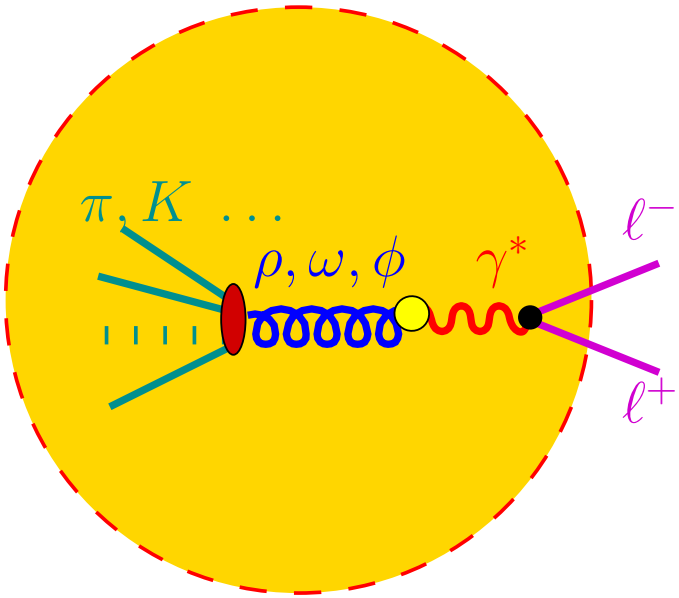
- direct probes for in-medium properties of partons and hadrons (negligible final-state interactions)
- emitted from all stages of the produced medium
- related to fundamental properties of QCD: chiral phase transition

Theoretical Framework

- Dilepton rate and electromagnetic current-current correlator
- sources from all stages of the medium (need fireball evolution!)
  - thermal radiation from hot/dense hadron gas $\Rightarrow$ hadronic many-body theory
  - thermal radiation from quark-gluon plasma via HTL-improved pQCD
  - correlated open-charm decays
  - Drell Yan

Predictions for LHC

Electromagnetic probes in heavy-ion collisions



- hot and dense hadronic medium
  Low-mass dileptons from ρ, ω, ϕ decays
- no strong final-state interactions

$\Rightarrow$ direct probe of in-medium spectral properties of vector mesons

- at earlier hotter stages: thermal radiation from QGP

- experimental result: enhancement of dilepton rates around and below the ρ, ω-mass region compared to expectations from pp collisions
- attributed to medium effects on vector-meson properties

Vector Mesons and electromagnetic Probes

- dilepton thermal emission rates given by electromagnetic-current-correlation function ($J_\mu^{\rm QCD} = \sum_f Q_f \bar{\psi}_f \gamma_\mu \psi_f$)

$$\Pi^{\rm ret}_{\mu\nu}(q) = \int {\rm d}^4x \exp({\rm i}q\cdot x)\Theta(x^0) \left\langle J_\mu(0) J_\nu(x)\right\rangle_T$$

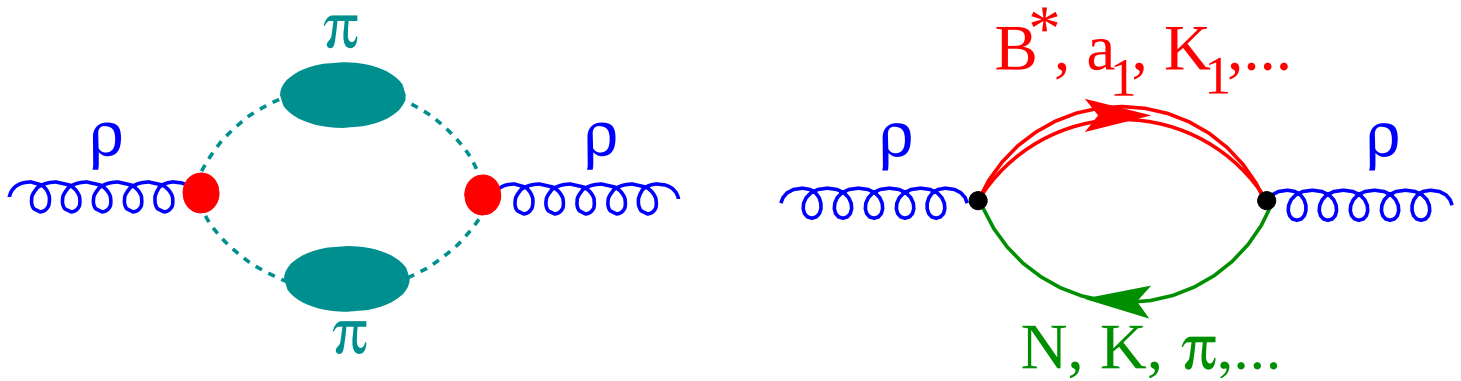
$$\frac{{\rm d}N_{\ell^+\ell^-}}{{\rm d}^4x{\rm d}^4q} = -\frac{\alpha_{\rm em}^2}{3q^2\pi^3}\Phi_{\ell^+\ell^-}(q^2) g^{\mu\nu}\,{\rm Im}\,\Pi^{\rm (ret)}_{\mu\nu}(q)\Big|_{q^2=M^2_{\ell^+\ell^-}} f_B(q_0)$$

[McLerran, Toimela 85; Gale, Kapusta 87, ...]

- correlators
  - in hadronic phase from effective hadronic models
  - in QGP phase from hard-thermal loop improved $q\bar{q} \to \ell^+\ell^-$
- directly related to chiral symmetry of QCD

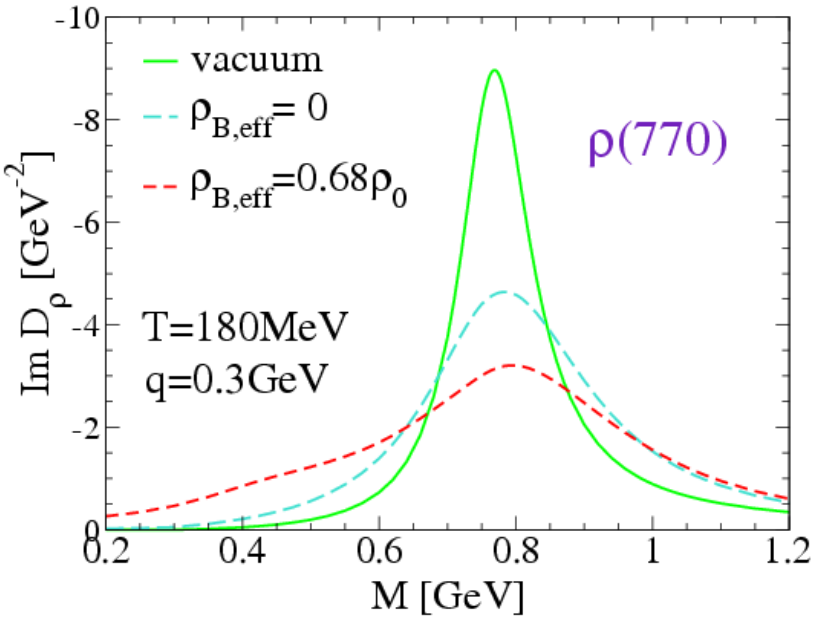
Hadronic Many-Body Theory (HMBT)

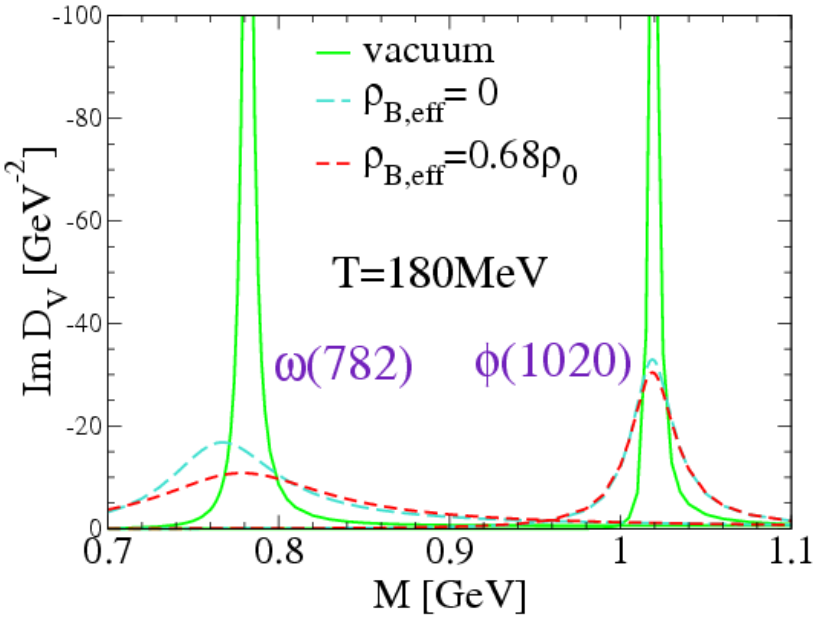
- Phenomenological HMBT [Chanfray et al, Herrmann et al, Rapp et al, ...] for vector mesons; constrained by decay widths, vacuum π-form factor, photo-absorption on nucleon and nuclei
- $\pi\pi$ interactions and baryonic excitations



- real parts of retarded selfenergy tend to cancel $\Rightarrow$ small mass shifts
- imaginary parts always negative $\Rightarrow$ large broadening of spectra
- Anti-/Baryons important even at RHIC and LHC (CP invariance of strong interactions)
- $M \geq 1$: onset of 4-pion continuum, possibly enhanced by chiral mixing: $\Pi_V = (1-\epsilon)\Pi_V^{(0)} + \epsilon\Pi_A^{(0)}$

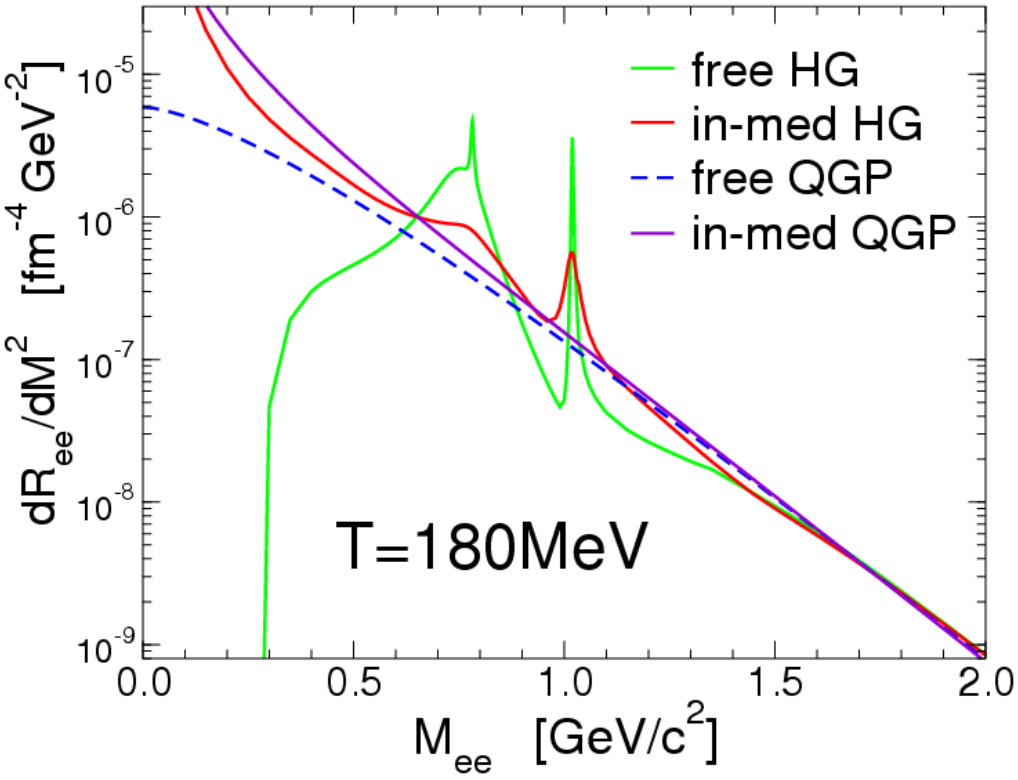
In-medium spectral functions and baryon effects





- baryon effects important $\leftrightarrow$ $N_B + N_{\bar{B}}$ relevant (not $N_B - N_{\bar{B}}$)
  - large contribution to broadening of the peak
  - responsible for most of the strength at small M

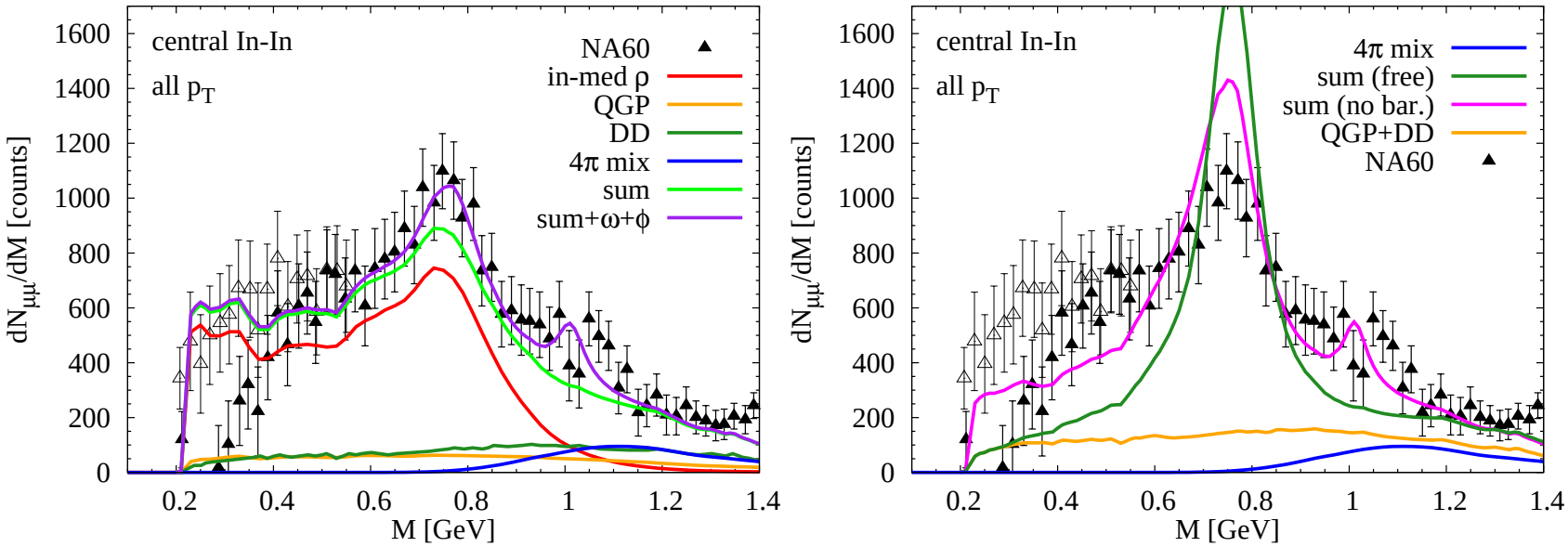
Dilepton rates: Hadron gas vs. QGP



- in-medium hadron gas matches with QGP
- similar results also for γ rates
- "quark-hadron duality"?

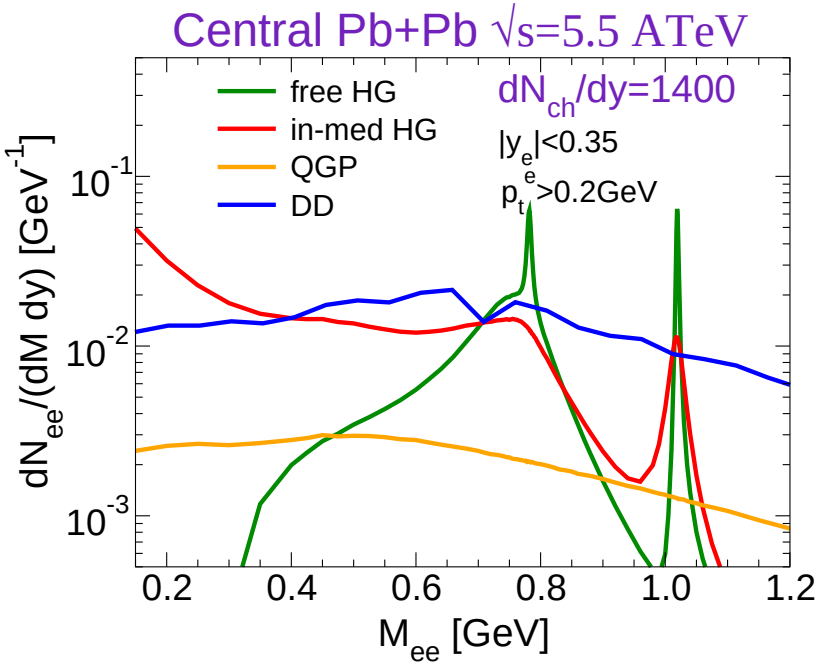
Dilepton-access spectrum and baryon effects

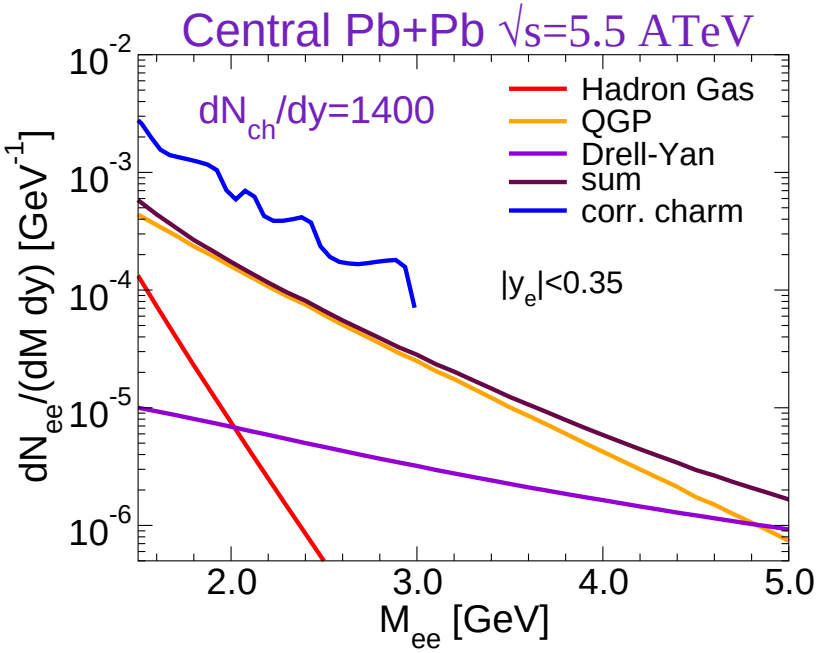
- convolute rate with fireball evolution
- isentropic expansion determines $T(\tau)$, $\mu_B(\tau)$, $\mu_\pi(\tau)$, ...
- total entropy determined by number of charged particles ($\mathrm{d}N/dy$)
- initial temperature depends on plasma formation time



- comparison with dimuon spectra in 158 AGeV-In-In collisions from NA60 (HvH, R. Rapp, PRL **97**, 102301 (2006))
- no baryons: not enough broadening, lack of strength below ρ peak

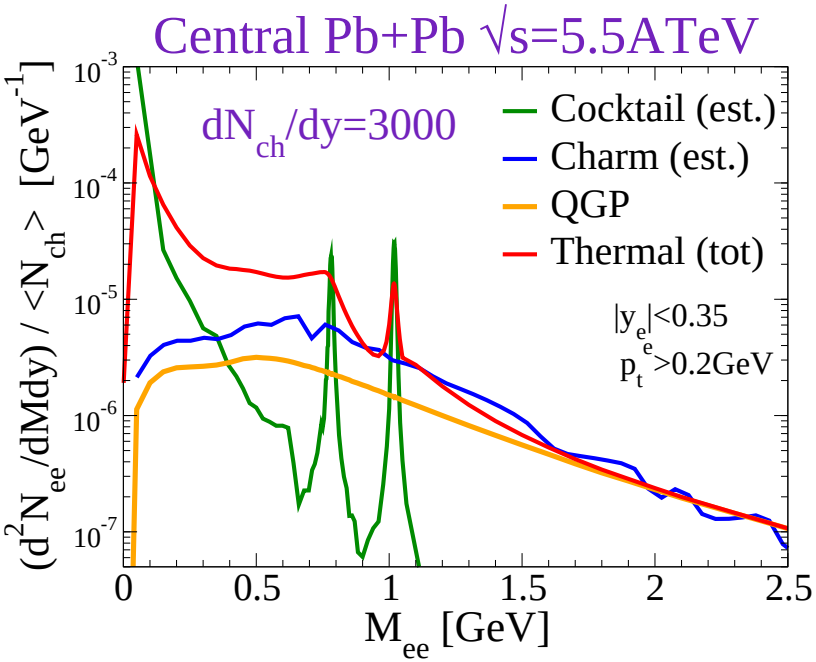
Predictions for LHC

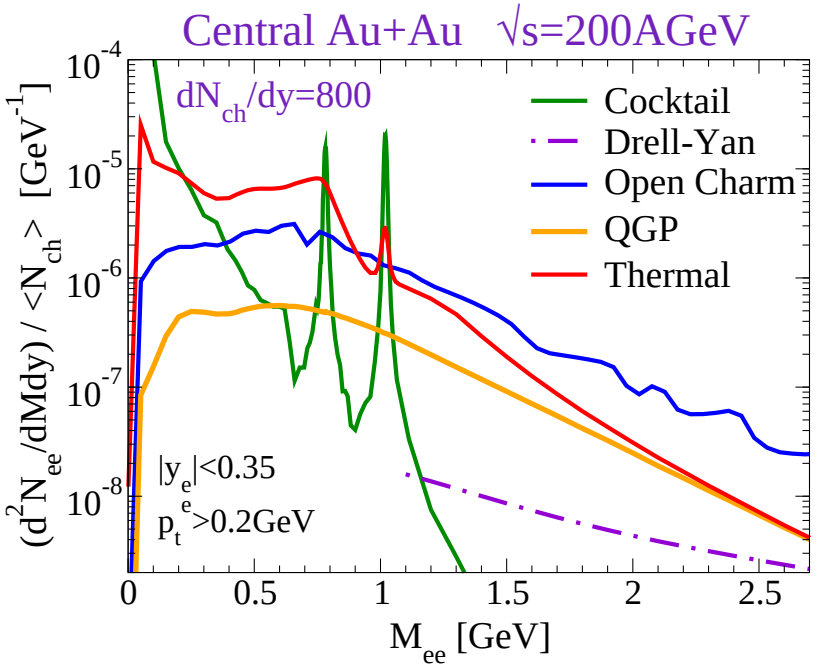




- large medium effects
- QGP subleading also at LHC
- Correlated open-charm decays ($\sigma_c^{\mathrm{LHC}} = 5$ mb)
  - comparable with thermal radiation from hadron gas
  - energy loss?
  - open-bottom decays?

LHC vs. RHIC





- at higher $\mathrm{d}N/\mathrm{d}y$ thermal radiation from hadron gas dominant for $M \lesssim 1$ GeV
- for $M \gtrsim 1$ GeV: $D\bar{D}$ comparable (but no energy loss considered!)

Conclusions

- low-mass dileptons sensitive to fundamental principles of QCD (restoration of chiral symmetry)
- Hadronic many-body theory + HTL-improved pQCD for QGP
  - importance of baryon effects (not $n_B - n_{\bar{B}}$ but $n_B + n_{\bar{B}}$ relevant)
  - "Quark-Hadron Duality"?
- Electromagnetic probes at LHC
  - relatively stronger thermal radiation from QGP than at RHIC
  - thermal signal $\leftrightarrow$ correlated $D\bar{D}$ ($B\bar{B}$?)
  - heavy-quark energy loss