

# Dileptons at LHC

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# Outline

## Electromagnetic probes in heavy-ion collisions

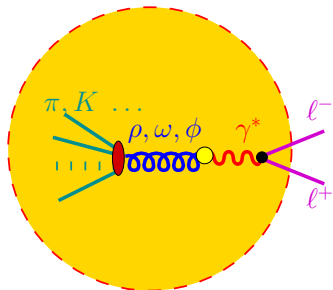
- ▶ **direct probes** for **in-medium properties of partons and hadrons** (negligible final-state interactions)
- ▶ emitted from all stages of the produced **medium**
- ▶ related to fundamental properties of QCD: **chiral phase transition**

## 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  $\rho, \omega, \phi$  decays
  - ▶ no strong final-state interactions
  - ⇒ 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  $\rho, \omega$ -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

$$(J_\mu^{\text{QCD}} = \sum_f Q_f \bar{\psi}_f \gamma_\mu \psi_f)$$

$$\Pi_{\mu\nu}^{\text{ret}}(q) = \int d^4x \exp(iq \cdot x) \Theta(x^0) \langle J_\mu(0) J_\nu(x) \rangle_T$$

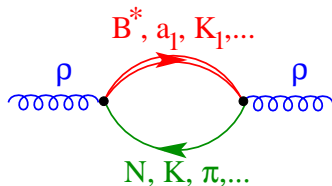
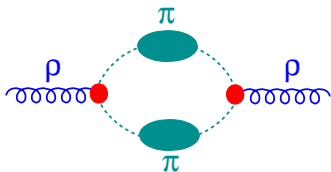
$$\frac{dN_{\ell^+\ell^-}}{d^4x d^4q} = -\frac{\alpha_{\text{em}}^2}{3q^2 \pi^3} \Phi_{\ell^+\ell^-}(q^2) g^{\mu\nu} \text{Im} \Pi_{\mu\nu}^{\text{(ret)}}(q) \Big|_{q^2=M_{\ell^+\ell^-}^2} f_B(q_0)$$

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

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

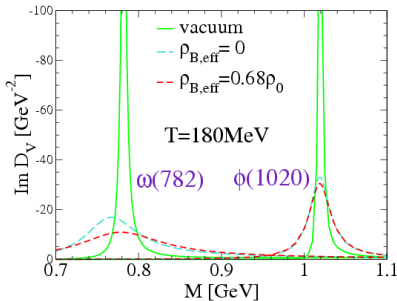
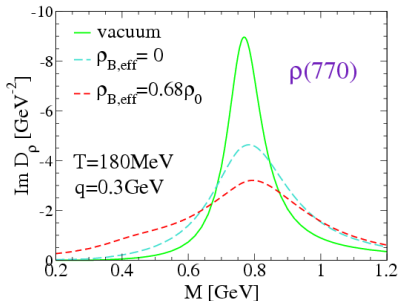
# Hadronic Many-Body Theory (HMBT)

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



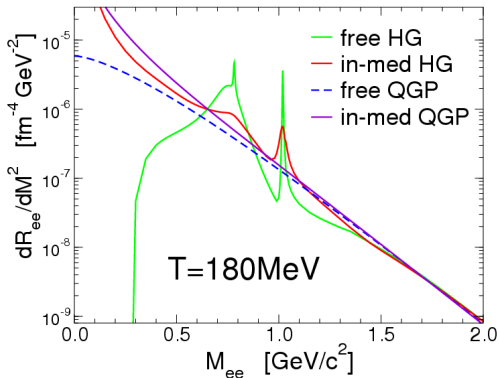
- ▶ real parts of retarded selfenergy tend to cancel  $\Rightarrow$  **small mass shifts**
- ▶ imaginary parts always negative  $\Rightarrow$  **large broadening of spectra**
- ▶ **Anti-/Baryons** important even at RHIC and LHC  
(CP invariance of strong interactions)
- ▶  **$M \geq 1$ : onset of 4-pion 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  $M$

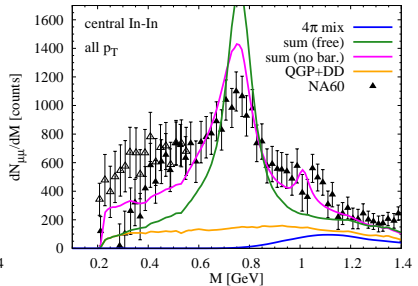
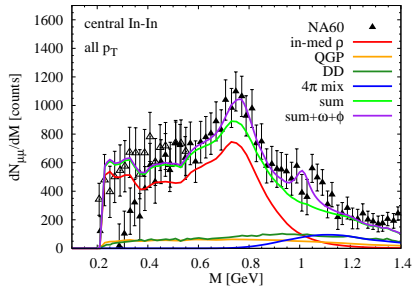
# Dilepton rates: Hadron gas vs. QGP



- ▶ in-medium **hadron gas** matches with **QGP**
- ▶ similar results also for  $\gamma$  rates
- ▶ “**quark-hadron duality**”?

# Dilepton-access spectrum and baryon effects

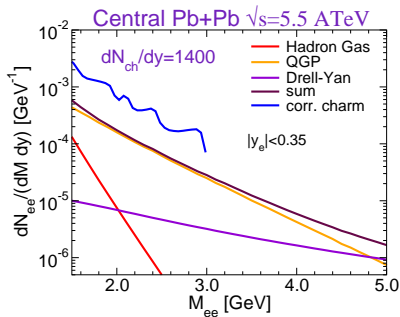
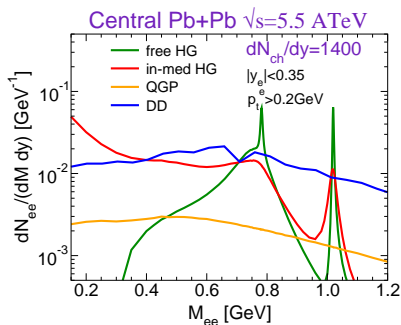
- ▶ convolute rate with **fireball evolution**
- ▶ **isentropic expansion** determines  $T(\tau)$ ,  $\mu_B(\tau)$ ,  $\mu_\pi(\tau)$ , ...
- ▶ total entropy determined by **number of charged particles** ( $dN/dy$ )
- ▶ initial temperature depends on **plasma formation time**



- ▶ 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  $\rho$  peak**

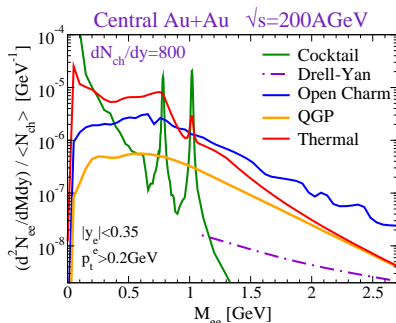
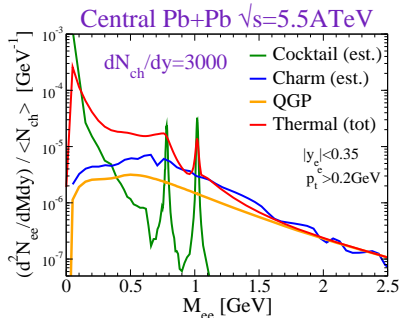


# Predictions for LHC



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

# LHC vs. RHIC



- ▶ at **higher  $dN/dy$**  thermal radiation from hadron gas dominant for  $M \lesssim 1 \text{ GeV}$
- ▶ for  $M \gtrsim 1 \text{ GeV}$ :  $D\bar{D}$  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