Medium Modifications of vector mesons and NA60 Dilepton Data

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Outline

Vector Mesons and electromagnetic Probes

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

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

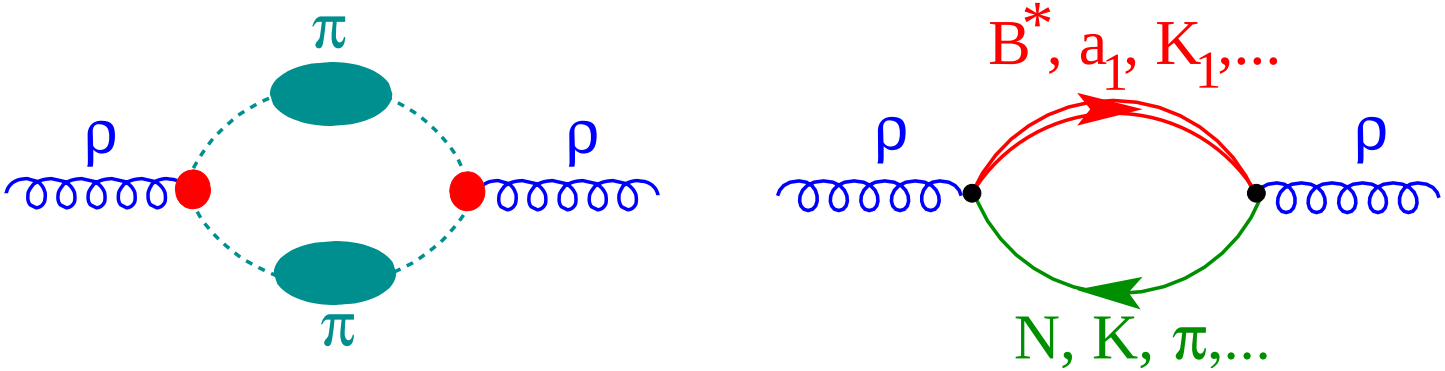
$$\frac{{\rm d}N_{\ell^+\ell^-}}{{\rm d}^4x{\rm d}^4q} = -\frac{\alpha_{\rm em}^2}{3q^2\pi^3}\Phi_{\ell^+\ell^-}(q^2)g^{\mu\nu}\,{\rm Im}\,\Pi_{\mu\nu}^{\rm (ret)}(q)\Big|_{q^2=M_{\ell^+\ell^-}^2} f_B(q_0)$$

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

- correlators evaluated from effective hadronic models
- directly related to chiral symmetry of QCD

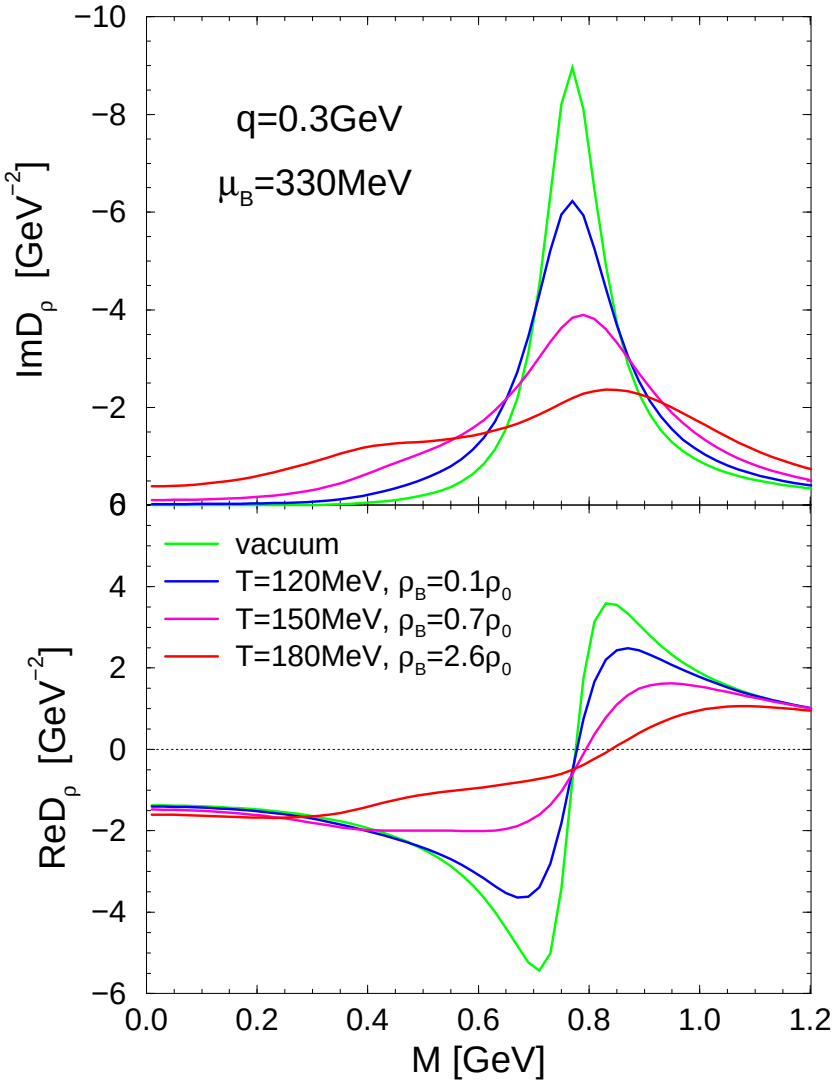
Hadronic Many-Body Theory (HMBT)

- Phenomenological HMBT [Chanfray et al, Herrmann et al, Rapp et al, ...] for vector mesons; constrained by
- $\pi\pi$ interactions and baryonic excitations



- Anti-/Baryons important even at RHIC (CP invariance of strong interactions)
- $M \geq 1$: onset of 4-pion continuum, possibly enhanced by chiral mixing: $\Pi_V = (1-\epsilon)\Pi_V^{(0)} + \epsilon\Pi_A^{(0)}$

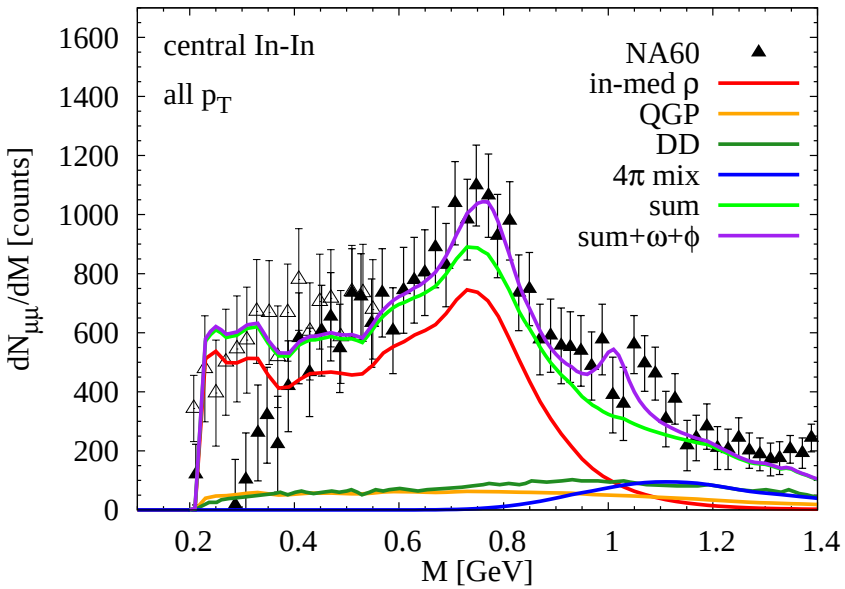
Hadronic Many-Body Theory (HMBT)



- small mass shifts, large broadening
- reason:
  - real parts of self-energy contributions tend to cancel
  - imaginary parts always of same sign
- baryons $\Rightarrow$ strength below ρ peak

In-medium ρ, ω and ϕ + Four-Pion Continuum

- homogeneous Fireball model for time evolution
- isentropic expansion: QGP ($T_i \simeq 197$ MeV) via mixed phase ($T_c = 175$ MeV) to thermal freeze-out ($T \simeq 120$ MeV)

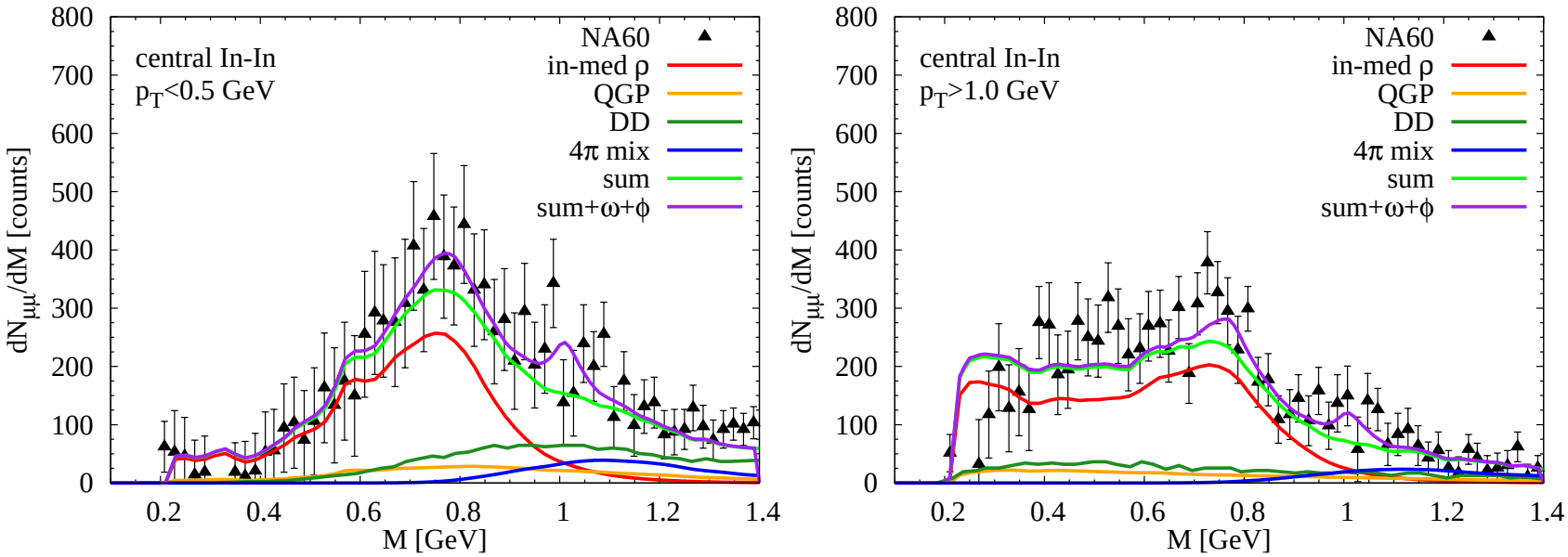


- relative normalization of thermal components fixed by in-medium em. spectral functions
- absolute normalization $\Leftrightarrow$ fireball lifetime
- good overall agreement with data

- NB: freeze-out ρ $\Leftrightarrow$ here: run fireball for 1 fm/c longer

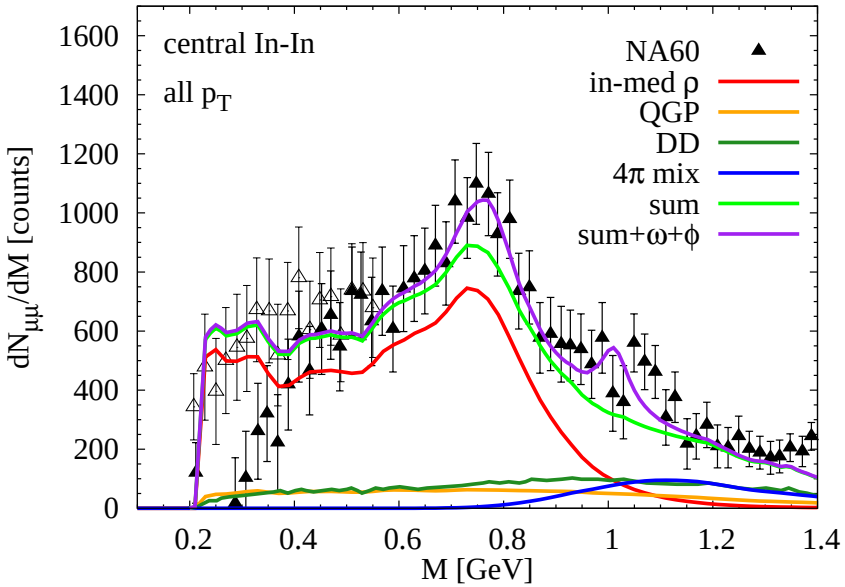
[HvH, R. Rapp, PRL **97**, 102301 (2006)]

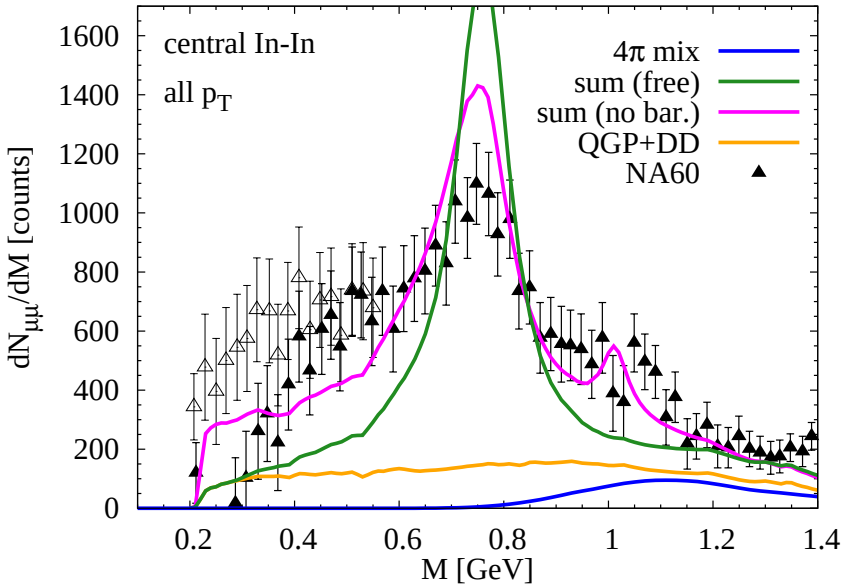
In-medium ρ, ω and ϕ + Four-Pion Continuum (p_T slices)



- good description in different p_T bins

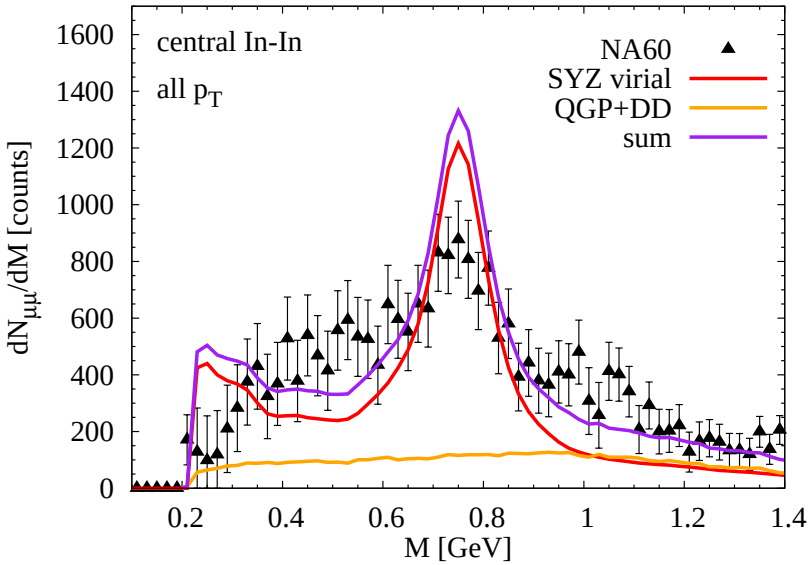
Baryon Effects

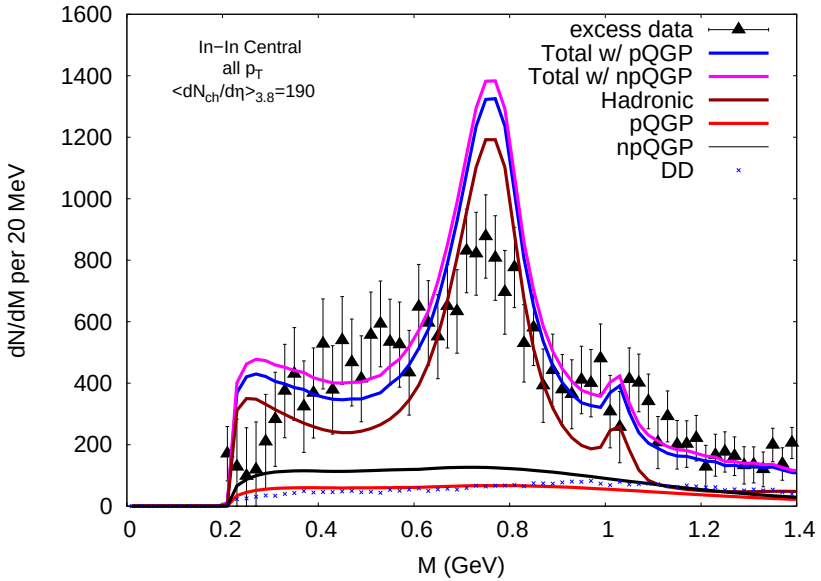




- without baryons
  - not enough broadening
  - lack of strength below ρ peak

Chiral Reduction Formalism (Virial Expansion)

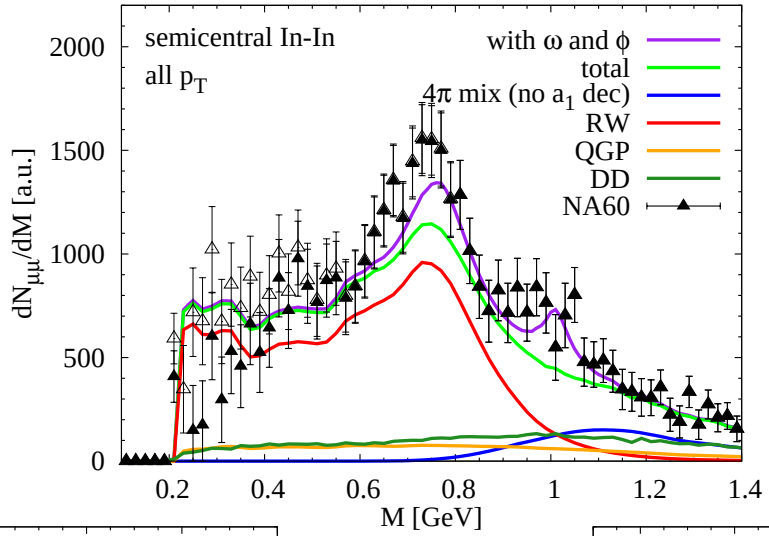


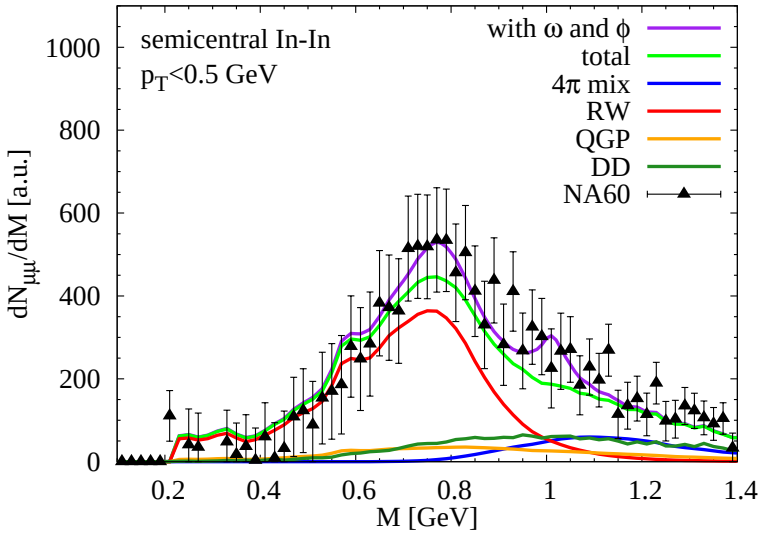


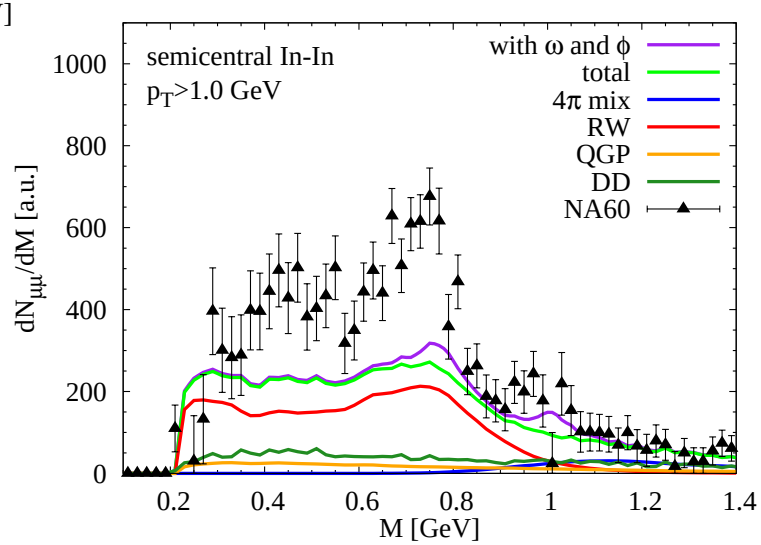
[HvH, Rapp hep-ph/0604269] [Dusling, Teaney, Zahed 06]

- underestimates medium effects on the ρ
  (due to low-density approximation no broadening!)
- results with fireball parametrization very similar to hydro!

In-medium ρ, ω and ϕ + 4-Pion Continuum (semicentral)



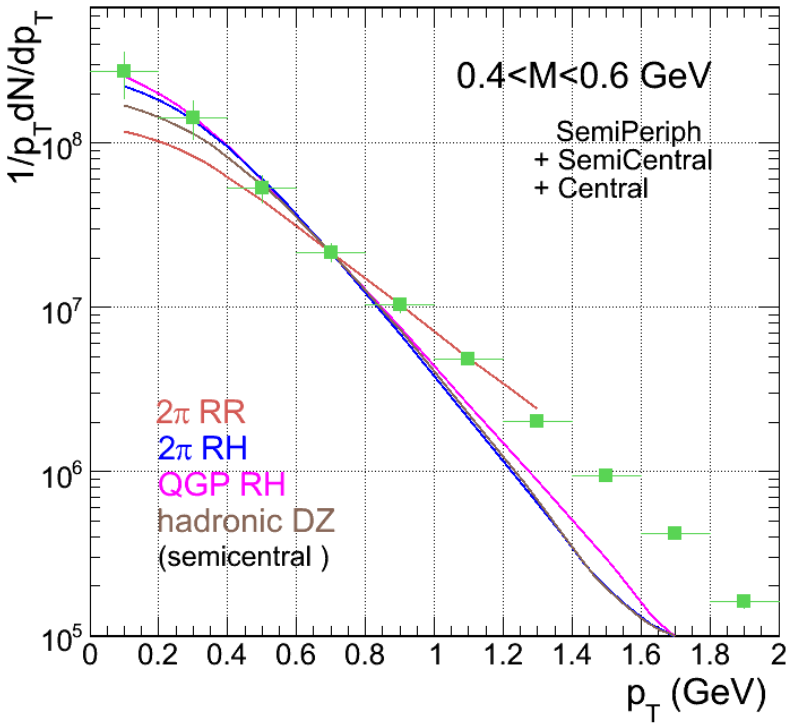


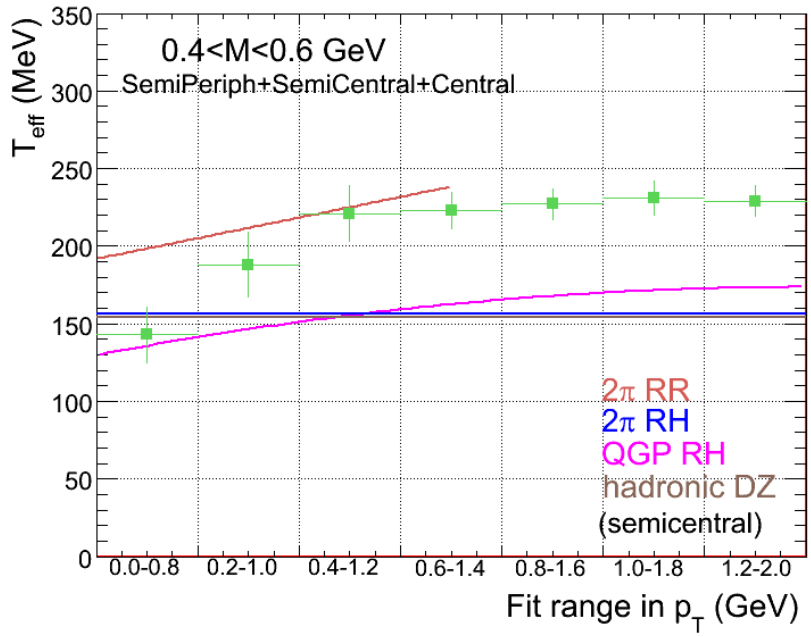


missing yield at high p_T: "Corona/freeze-out effect"

p_T spectra (model comparison)

- p_T spectra more sensitive to flow than to spectral shape!
- for thermal emission: Fireball model in close agreement with hydro calculation [Dusling, Teaney, Zahed 06]
- harder spectra in fireball model of [Ruppert, Renk 06]





[S. Damjanovic, talk at HP06]

Refined components of dilepton emission in HIC's

1. initial hard processes: Drell Yan
2. "core" $\Leftrightarrow$ emission from thermal source

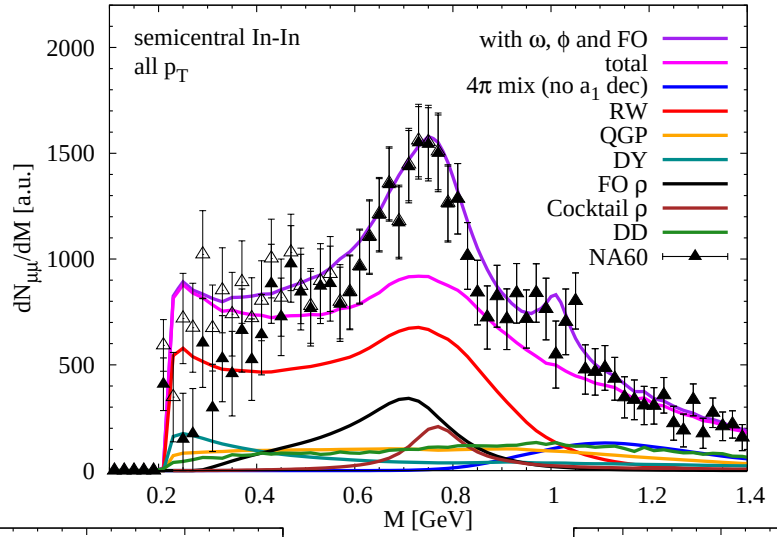
$$\frac{1}{p_T}\frac{\mathrm{d}N^{(\text{thermal})}}{\mathrm{d}M\mathrm{d}p_T} = \int \mathrm{d}^4x \int \mathrm{d}y \int M\mathrm{d}\varphi \frac{\mathrm{d}N^{(\text{thermal})}}{\mathrm{d}^4x\mathrm{d}^4q}\mathrm{Acc}(M,p_T,y)$$

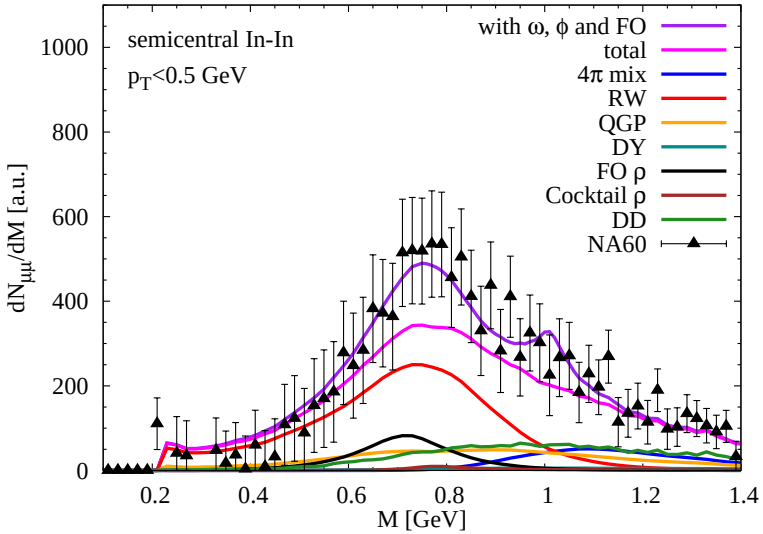
3. "corona" $\Leftrightarrow$ emission from "cocktail" mesons
4. after thermal freeze-out $\Leftrightarrow$ emission from "freeze-out" mesons

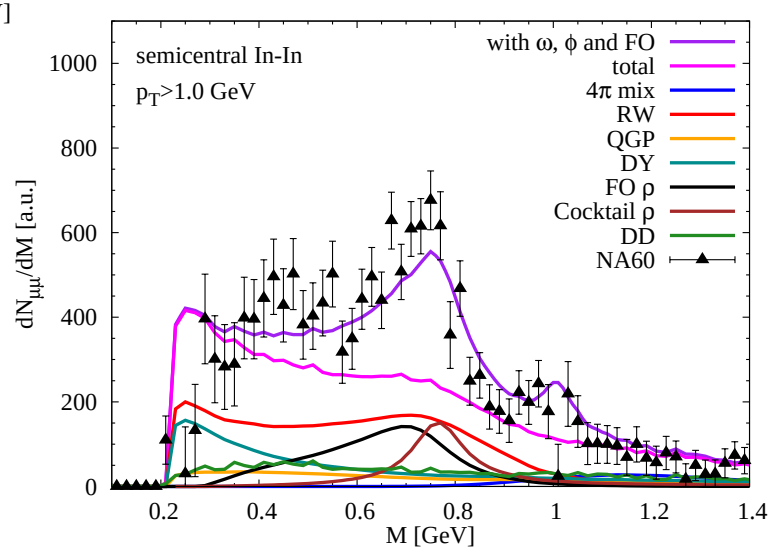
$$\mathrm{d}N^{(\text{fo})} = \frac{\mathrm{d}^3p}{p_0}p_\mu \mathrm{d}\sigma^\mu f_B(u_\mu p^\mu/T)\frac{\Gamma_{\text{meson}\to\ell^+\ell^-}}{\Gamma_{\text{meson}}}\mathrm{Acc}$$

for our model: sudden freeze-out $\Rightarrow$ additional factor
$\gamma_{\text{meson}} = p_0/M$ compared to thermal emission
dilation of meson's lifetime

Hadronic Many Body Theory (semicentral)







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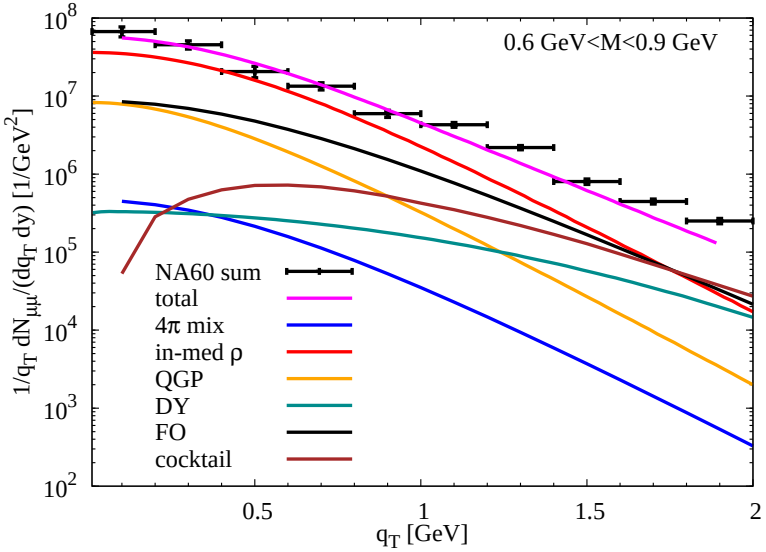

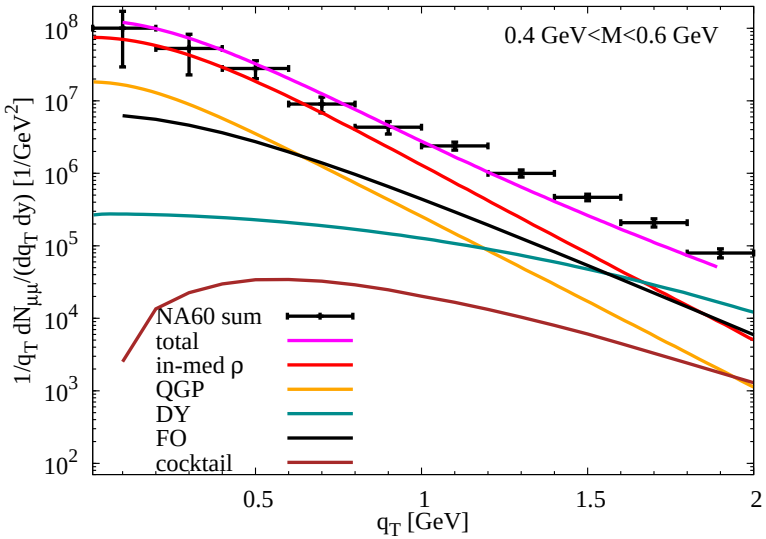

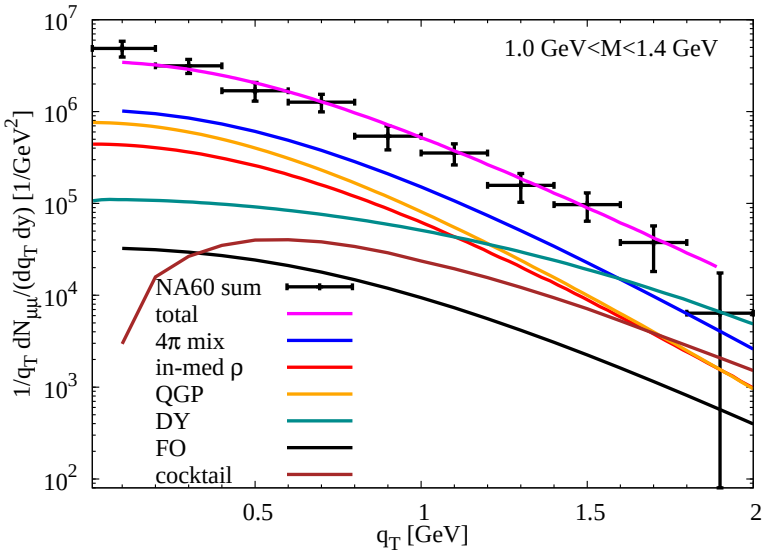

Conclusions and Outlook

- Dilepton spectra $\Leftrightarrow$ em. current correlator
- directly related to chiral symmetry
  (vector and axial-vector currents)
- phenomenological hadronic many-body theory
  - low-mass region: light vector mesons
  - intermediate-mass region: four-pion continuum
- medium effects
  - baryons essential for in-medium properties of vector mesons
  - chiral mixing
  - radiation from QGP rather small for In-In
- fireball/freeze-out dynamics $\Leftrightarrow$ p_T spectra
  - High-precision Pb-Pb data $\Leftrightarrow$ medium effects more pronounced
- a lot for theory to do
  - implementation of chiral symmetry (including baryons!)
  - vector/axial-vector correlators $\Leftrightarrow$ chiral and QCD sum rules