

# In-medium Modifications of Hadrons and the NA60 dimuon measurements

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# Outline

Why Electromagnetic Probes?

Models for dilepton production in HIC's

Comparison to NA60 di-muon data

# Why Electromagnetic Probes?

- ▶  $\gamma, l^\pm$ : no strong interactions
- ▶ reflect whole "history" of collision

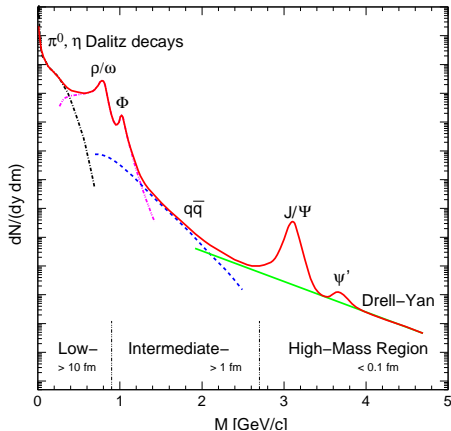
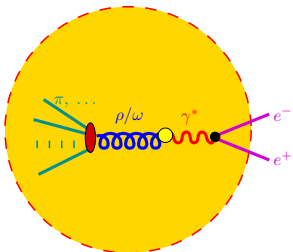
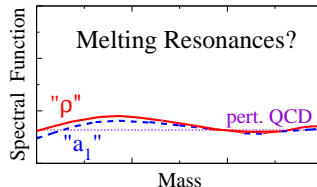
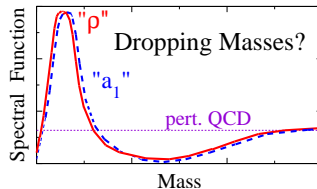
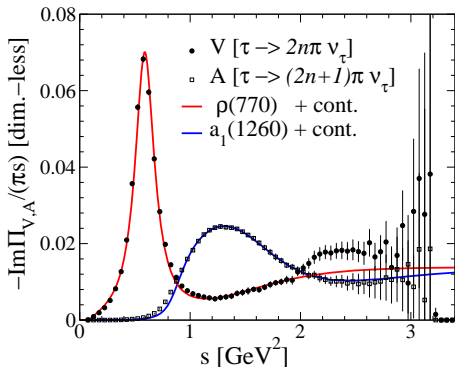


Fig. by A. Drees

# Vector Mesons and chiral symmetry

- ▶ dilepton rates  $\Leftrightarrow$  electromagnetic current-correlation functions
- $\Rightarrow$  probes chiral vector current
- ▶ hadronic em. current  $\Leftrightarrow$  spectral properties of vector mesons
- ▶ study medium modifications of hadrons in HIC's




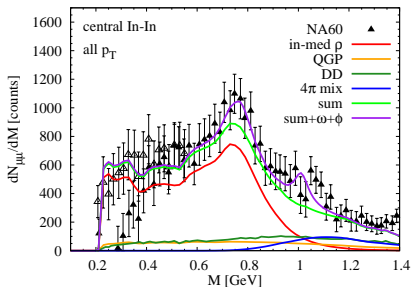
# Models

- ▶ confront different models for low-mass region with **di-muon data in 158 GeV In-In Collisions** [NA60 Collaboration]
  1. **Hadronic Many Body Theory**  
for medium modifications of  $\rho$  mesons [Rapp, Wambach 99]  
+ **chiral vector-axial-vector mixing** [HvH, Rapp 06]
  2. **virial expansion within chiral reduction formalism**  
[Steele, Yamagishi, Zahed 97]
  3. Scenario with (parameterized) **dropping  $\rho$  masses**
  4.  $\rho$ -spectral function from **Hidden Local Symmetry**  
[Harada, Sasaki 06]
- ▶ medium described with **thermal fireball parametrization** compatible with hydro models

# Hadronic Many-Body Theory + Chiral Mixing

- ▶ intermediate mass range: **Mixing** of  $\Pi_V$  with  $\Pi_A$   
 (Dey, Eletsky, Ioffe '90)

$$\Pi_V^{(T)} = (1 - \epsilon)\Pi_V + \epsilon\Pi_A, \quad \epsilon = \frac{1}{2} \frac{\mathcal{T}_\pi(T, \mu_\pi)}{\mathcal{T}_\pi(T_c, 0)} \propto \text{diagram}$$





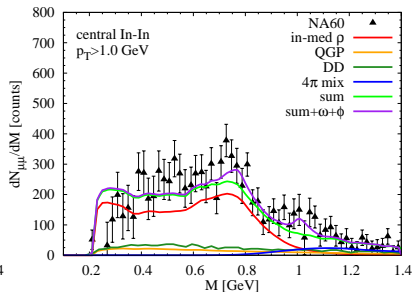
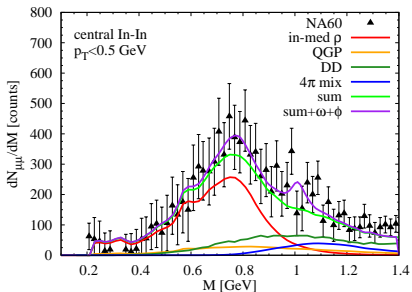
[HvH, R. Rapp, PRL **97**, 102301 (2006)]

- ▶ **Fireball model**  $\Rightarrow$  time evolution
- ▶ **absolute normalization!**
- ▶ **good overall agreement with data**
- ▶ **consistent with  $\omega$  and  $\phi$**
- ▶  $\omega$ : similar model as for  $\rho$
- ▶  $\phi$ : less well known; width assumed  $\simeq 80$  MeV

# Hadronic Many-Body Theory + Chiral Mixing

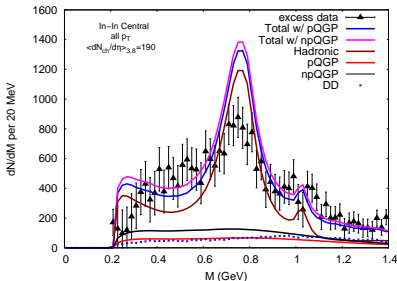
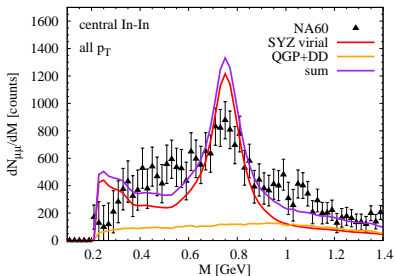
- ▶  $2\pi$  contributions +  $\rho B$  interactions from Rapp+Wambach '99
- ▶ intermediate mass range: **Mixing** of  $\Pi_V$  with  $\Pi_A$

$$\Pi_V^{(T)} = (1 - \epsilon)\Pi_V + \epsilon\Pi_A, \quad \epsilon = \frac{1}{2} \frac{\mathcal{T}_\pi(T, \mu_\pi)}{\mathcal{T}_\pi(T_c, 0)} \propto \text{diagram}$$




- ▶ **same absolute normalization!**

# Chiral Reduction Formalism (Virial Expansion)



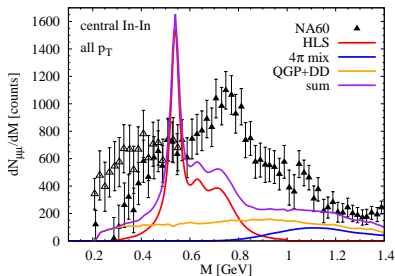
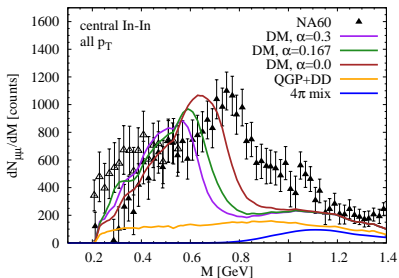
[HvH, Rapp hep-ph/0604269] [Dusling, Teaney, Zahed 06]

- ▶ **underestimates medium effects** on the  $\rho$   
 (due to low-density approximation no broadening!)
- ▶ intermediate masses: **mixing less pronounced**
- ▶ indication of chiral restoration?
- ▶ results with fireball parametrization consistent with hydro!



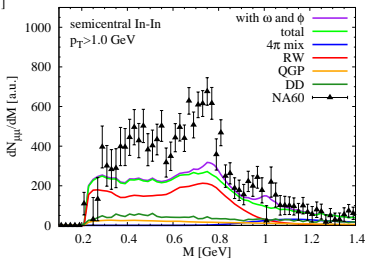
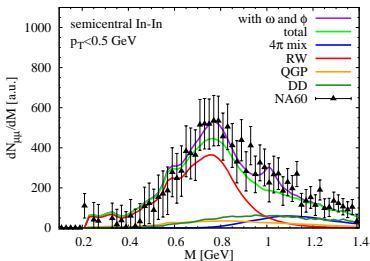
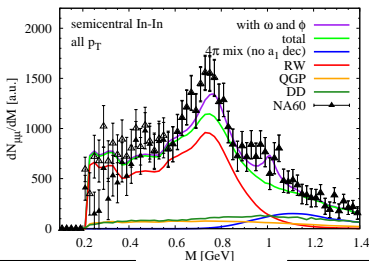
## Dropping $\rho$ masses/HLS?

$$m_\rho^* = m_\rho(1 - c\rho_B/\rho_0)[1 - (T/T_c)^2]^\alpha$$



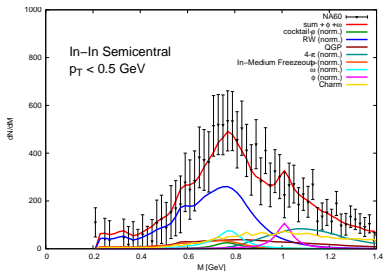
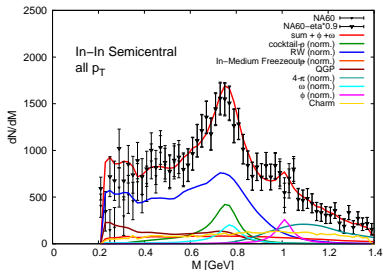
- ▶ **Naive** mass dropping not favored by NA60 data
- ▶ **Hidden local symmetry** [Harada, Sasaki 06]
- ▶ dropping mass + **narrowing of  $\rho$**  also not favored by data

# Hadronic Many Body Theory (semicentral)

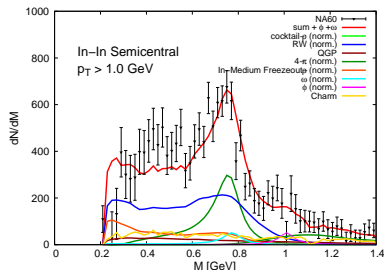


missing yield at high  $p_T$ : "Corona effect"?

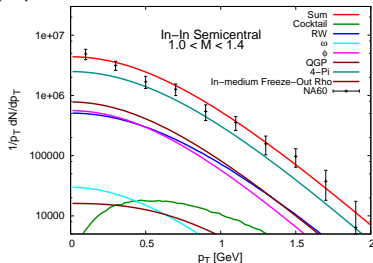
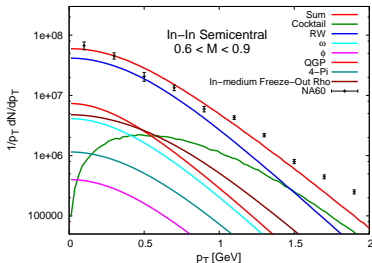
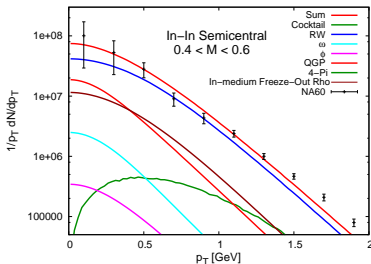
# Hadronic Many Body Theory (semicentral)



include cocktail and freeze-out  $\rho$   
 contribution from Drell-Yan?  
 work in progress  
 [Strong, HvH, Rapp 06]



# Hadronic Many Body Theory (semicentral)



work in progress [Strong, HvH, Rapp 06]

# Conclusions

- ▶ chiral symmetry: important feature to connect QCD ↔ hadronic effective models
- ▶ important property of (s)QGP:  
How is chiral symmetry restored?
- ▶ electromagnetic probes may provide most direct insight
- ▶ models vs. data: broadening of  $\rho$ , small mass shifts  
no  $\rho$ -mass dropping observed
- ▶ a lot to do for theory
  - ▶ consistent chiral scheme for hadrons
  - ▶ self-consistent treatment of (axial-) vector particles
  - ▶ equation of state including in-medium modifications vs. statistical models with “free hadron properties”