Chiral Mixing in Hot and Dense Matter

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Why chiral mixing?

Q. Do we see any signal of chiral symmetry restoration in dilepton measurement?

- ❑ Light vector mesons change their properties in hot/dense matter --- χ -sym. restoration?
- ❑ The best way: V spectrum vs. A spectrum
- ❑ Axial-vector mesons can show up in vector spectrum in a medium!

<VV> ← chiral mixing → <AA>

Chiral mixing in hot matter

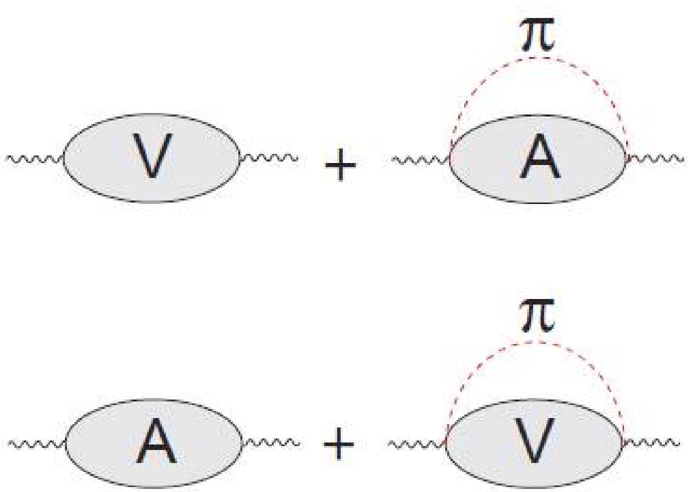
Low-energy theorem

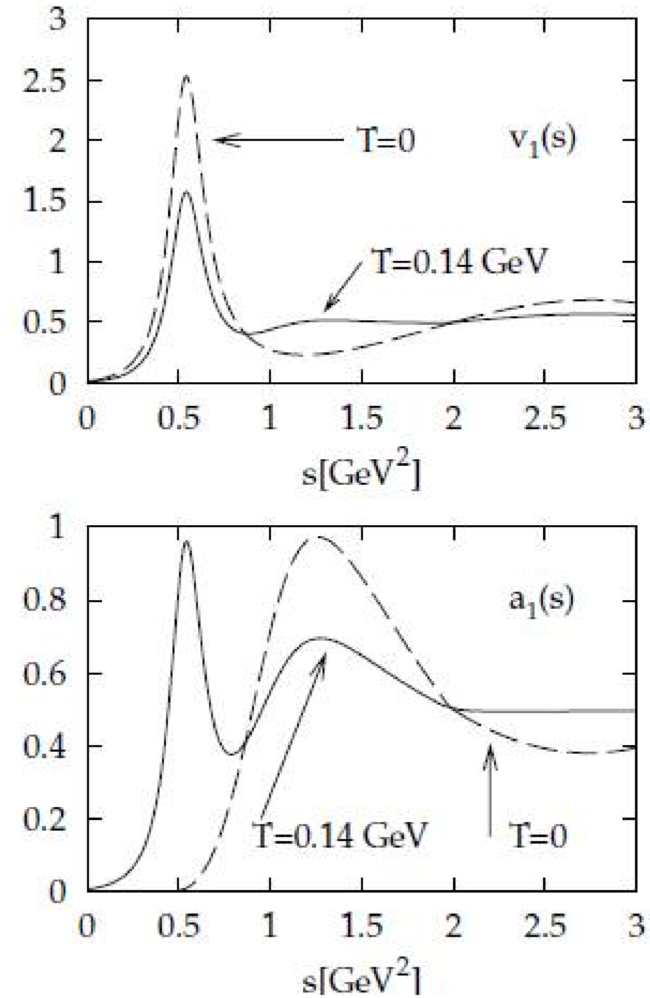
for low $T \lesssim m_\pi$: [Dey, Eletsky and Ioffe (90)]

$$G_V^{\mu\nu}(T) = (1-\epsilon) G_V^{\mu\nu}(0) + \epsilon\, G_A^{\mu\nu}(0)$$

$$G_A^{\mu\nu}(T) = (1-\epsilon) G_A^{\mu\nu}(0) + \epsilon\, G_V^{\mu\nu}(0)$$

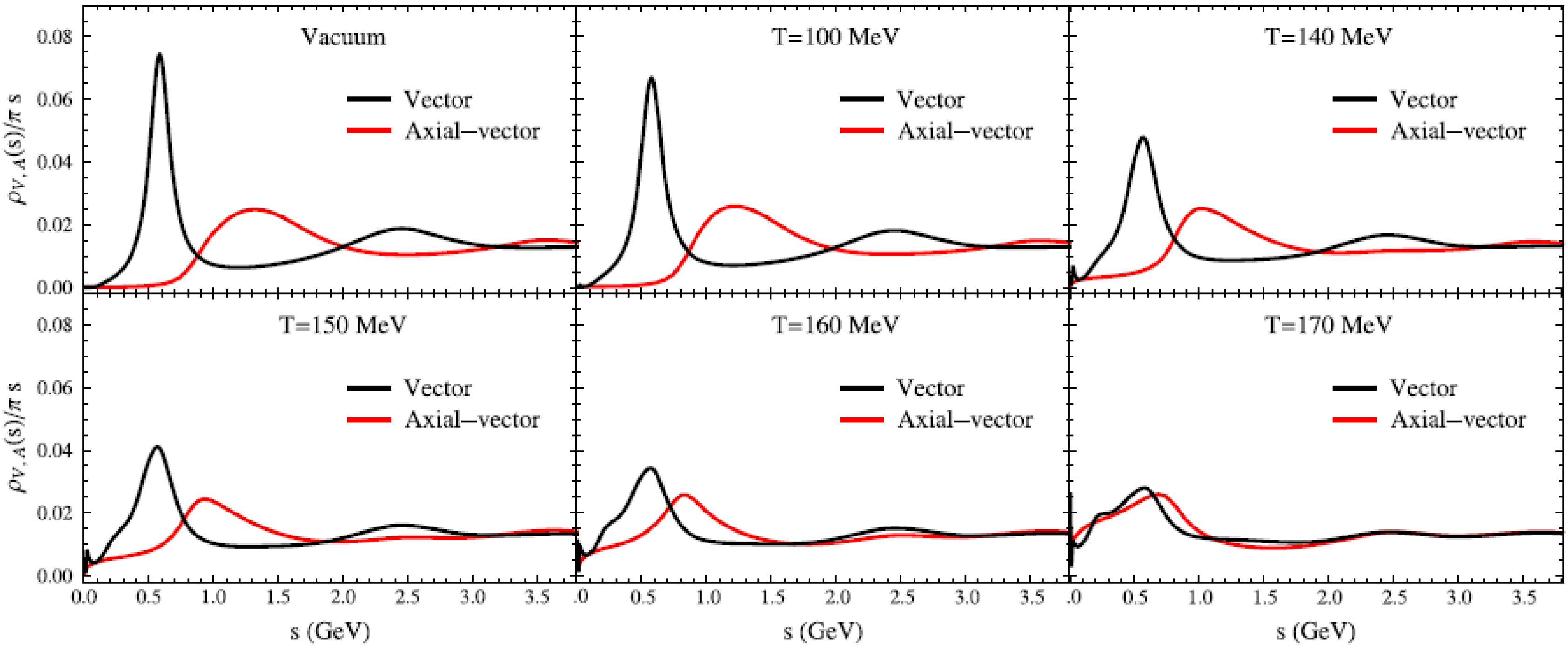
$$\epsilon = \frac{T^2}{6F_\pi^2}$$





[Hohler, Rapp ('14,'16)]

From low T to high T



- ❑ Weinberg SRs [Weinberg ('67); Kapusta, Shuryak ('94)]
- ❑ Vector SF & ansatz for a1 mass and width
  - ✓ Reduction of a1 mass, width broadening
  - ✓ Role of higher-lying states: ρ', a1', …

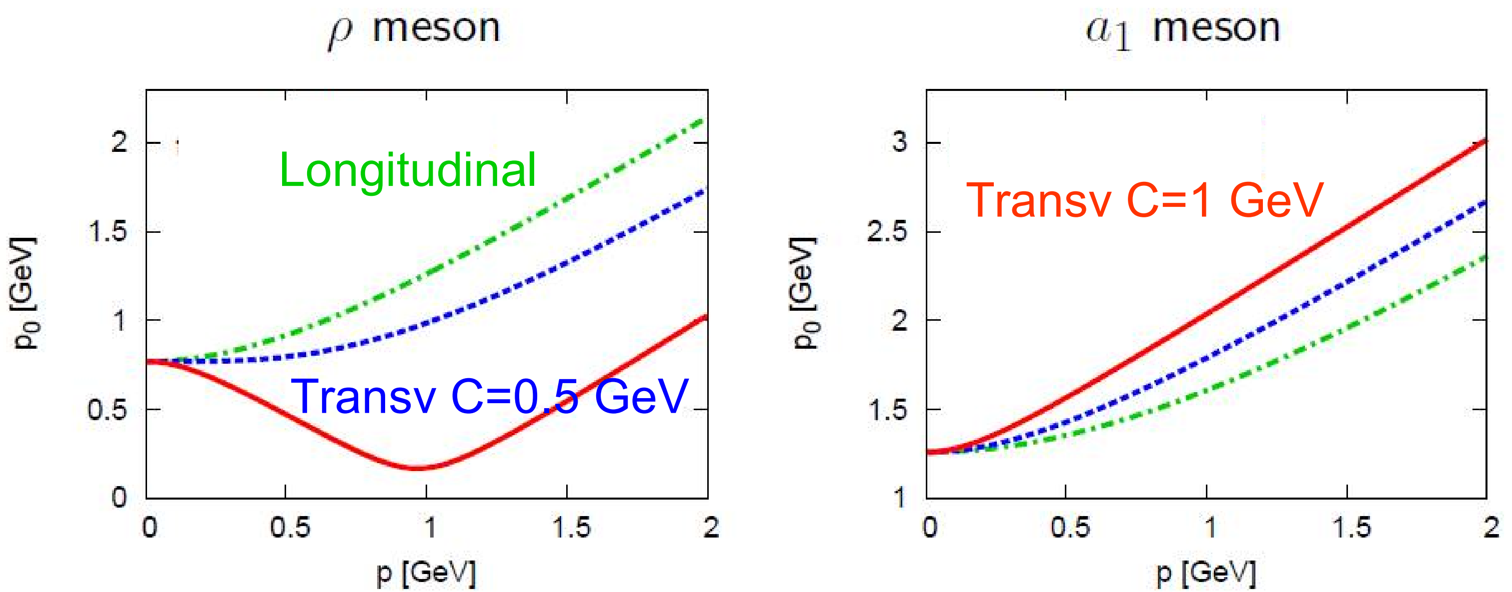
Chiral mixing in dense matter

[Domokos, Harvey ('07)]

Holographic approach

$$S_{4\text{dim}} = \int d^4x \left[\frac{1}{2}(\partial_\mu \pi)^2 - \frac{1}{2} m_\pi^2 \pi^2 - \frac{1}{4}(\rho_{\mu\nu})^2 - \frac{1}{4}(a_{\mu\nu})^2 + \frac{1}{2} m_\rho^2 \rho_\nu^2 + \frac{1}{2} m_a^2 a_\mu^2 + C\epsilon^{ijk}(\rho_i \partial_j a_k + a_i \partial_j \rho_k) \right]$$

$$p_0^2 - |\vec{p}|^2 = \frac{1}{2}\left[m_\rho^2 + m_{a_1}^2 \pm \sqrt{(m_{a_1}^2 - m_\rho^2)^2 + 16C^2|\vec{p}|^2} \right]$$



[Harada, CS ('09)]

Chiral mixing induced by WZW

- Wess-Zumino-Witten term [Kaiser, Meissner ('90)]

$$\mathcal{L}_{\omega\rho a_1} = g_{\omega\rho a_1}\epsilon^{\mu\nu\lambda\sigma}\omega_\mu\left[\partial_\nu V_\lambda \cdot A_\sigma + \partial_\nu A_\lambda \cdot V_\sigma\right]$$

$$\langle\omega_0\rangle = g_{\omega NN}\cdot n_B/m_\omega^2 \qquad C = g_{\omega\rho a_1}\cdot g_{\omega NN}\cdot\frac{n_B}{m_\omega^2}$$

- Mixing strength: C = 0.1 GeV at ρ_0
  - vs. AdS/QCD → C = 1 GeV at ρ_0
  - Why so large? --- higher-lying states in large Nc
  - Vector condensation at ρ_0!?

$$C_{\text{hQCD}} \sim C_{\omega\rho a_1} + \sum_n C_{\omega^n\rho a_1}$$

[Sakai and Sugimoto (2005)]

VDM from holography

- Infinite tower of vector mesons

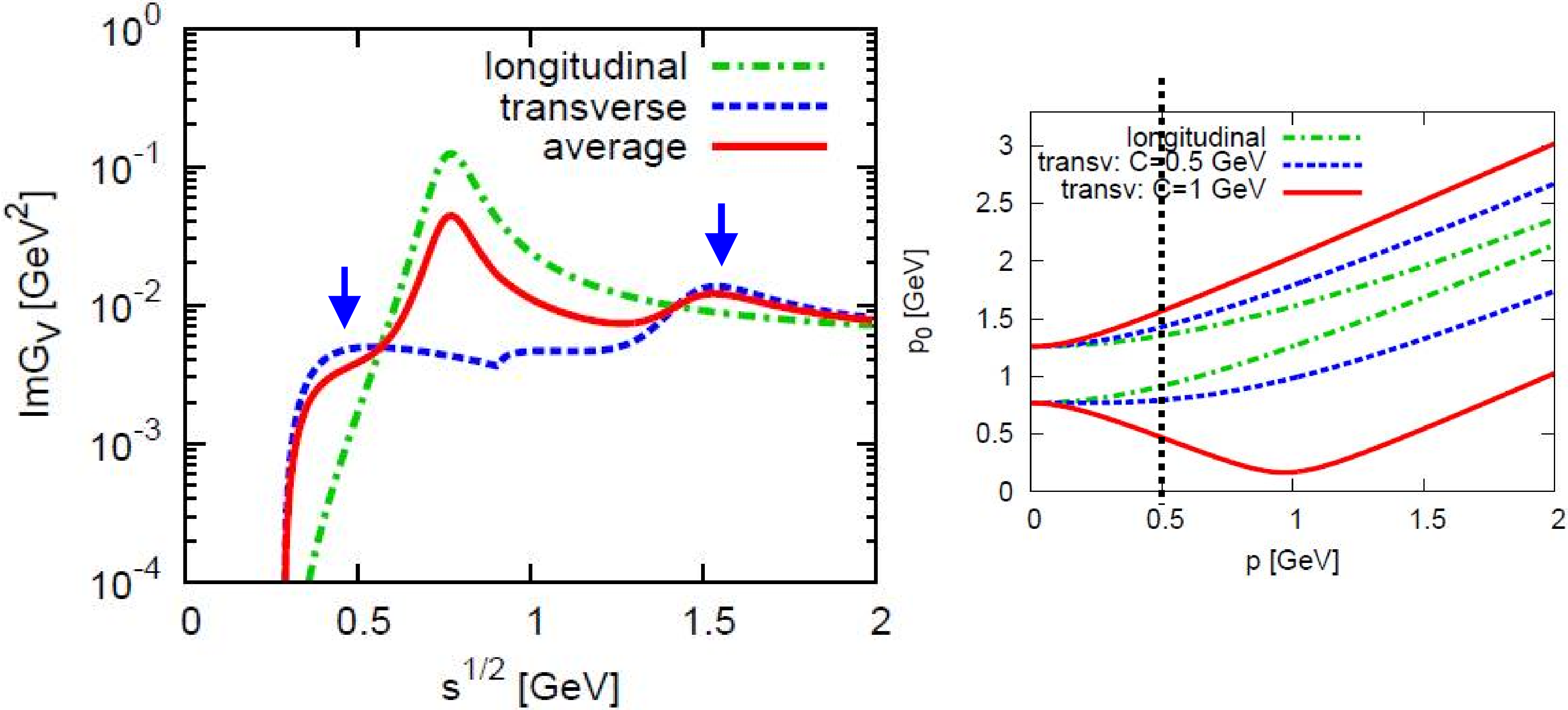
$$F(q^2) = \sum_{n=0}^{\infty} \frac{g_{\rho_n} \cdot g_{\rho_n \pi\pi}}{m_{\rho_n}^2 - q^2} \stackrel{q^2 \to 0}{\longrightarrow} 1$$

- Approximately saturated by the lowest 4

n	0	1	2
PDG	776	1465	1720
SS	776	1607	2435

$$F(0) = 1.31 - 0.35 + 0.05 - 0.01 = 1.00$$

Spectral function: Not BW

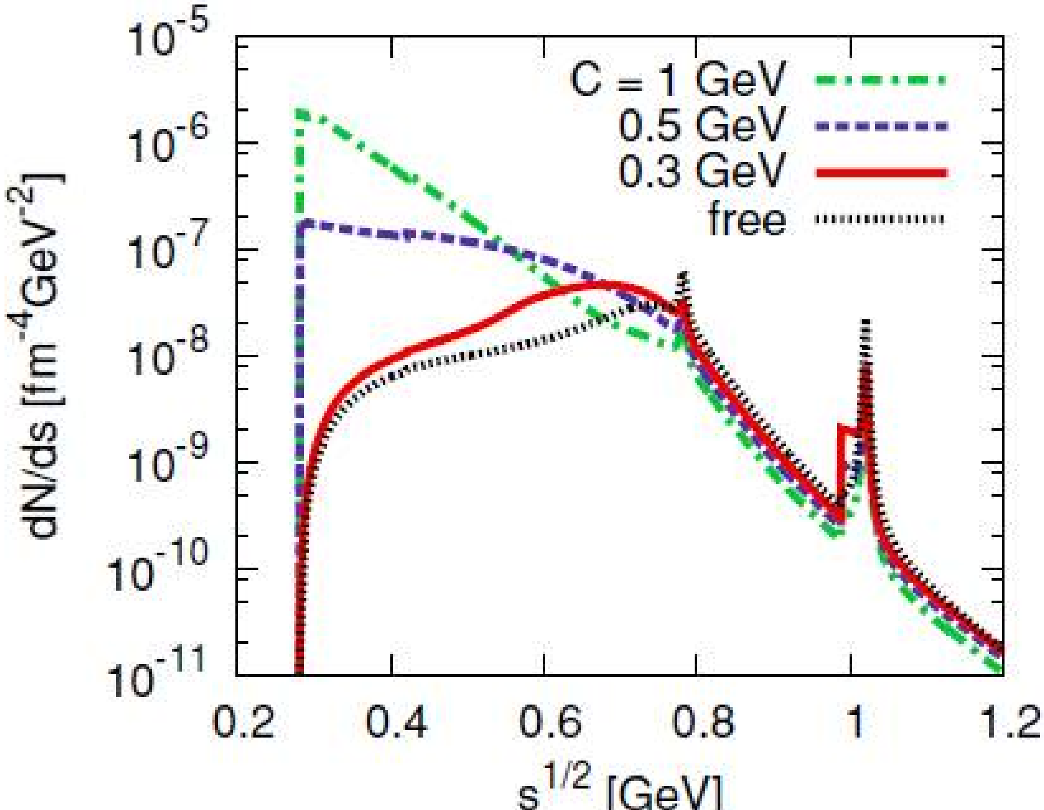


- C = 1 GeV, 3-momentum p = 0.5 GeV
- 1 peak of shifted rho, 1 peak of shifted a1

Dilepton rates at T = 100 MeV

- Propagator using $D_{V,A} = s - m^2_{\rho,a_1} + i m_{\rho,a_1}\Gamma_{\rho,a_1}(s)$

$$D_V^L = \frac{-1}{D_V}, \quad D_V^T = \frac{-D_A}{D_V D_A - 4C^2\vec{p}^2}$$



$$\frac{dN}{d^4p}(p_0, \vec{p}; T, n_B) = \frac{\alpha^2}{\pi^3 s}\frac{1}{e^{p_0/T} - 1}\mathrm{Im}G_V$$

$$\frac{dN}{ds}(s; T, n_B) = \int \frac{d^3\vec{p}}{2p_0}\frac{dN}{d^4p}$$

A missing piece: parity doubling

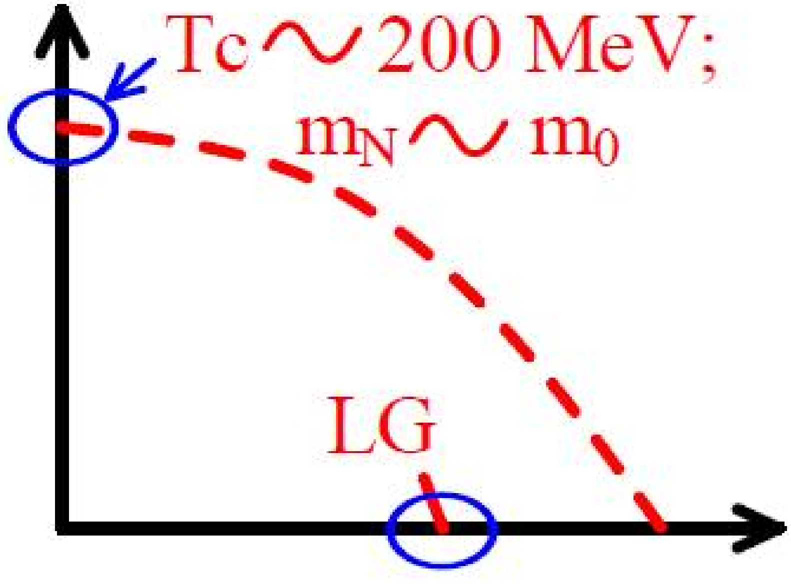
<AA> → <VV>

Set-up (1)

- ❑ Mass difference = order parameter
  - Chiral restoration → < σ >
  - Density effect → < ω_0 >

  } Chiral MF models

- ❑ Parity doublet model

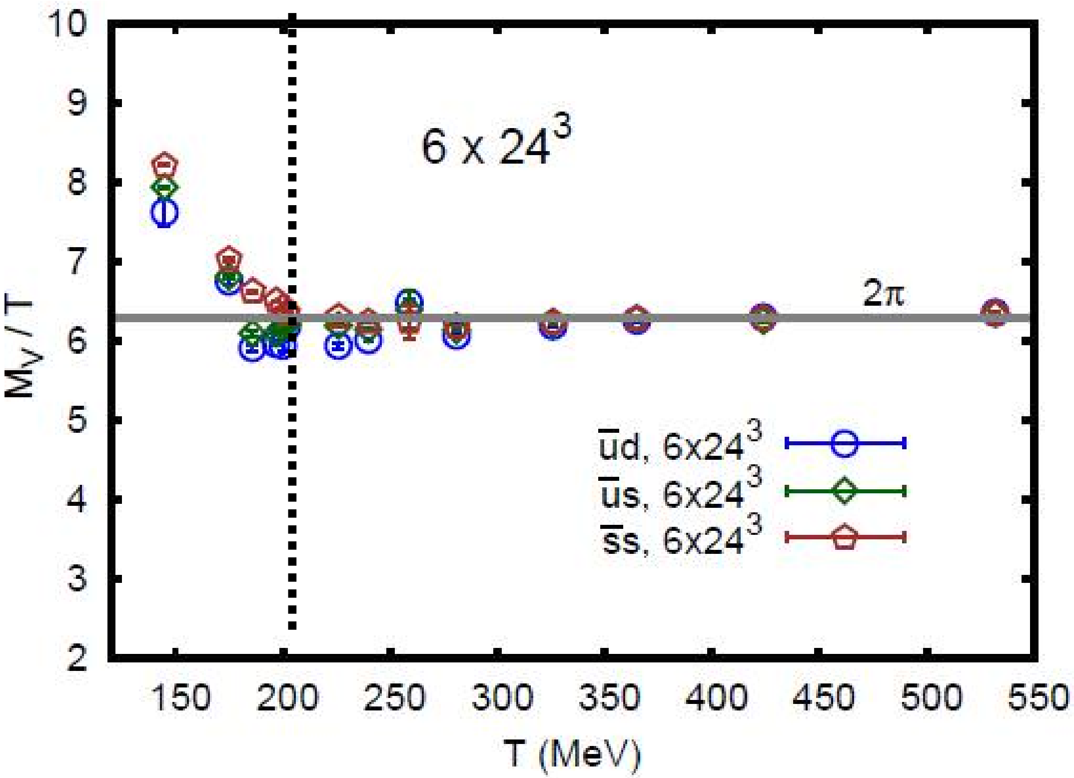


✓Tc at μ =0

✓Nuclear ground state

Set-up (2)

- Masses of Φ meson and $f_1(1420)$?
  - Screening mass in LQCD: modification sets in at Tc

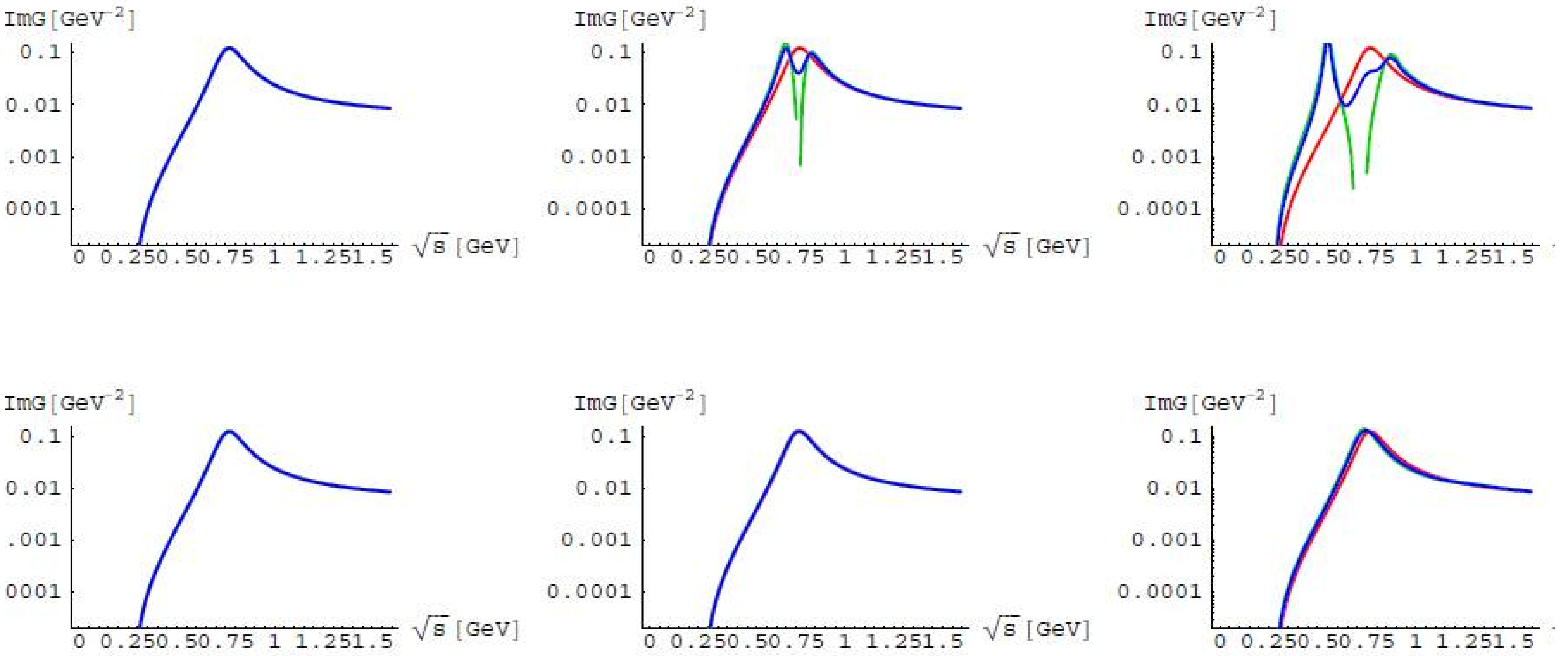


[Cheng et al., ('11)]

Assumptions:

- $\delta m(q) \approx 0$ at Tc
- $\delta m(s) \approx 0$ at 1.2 Tc
- Constant mass of vector states

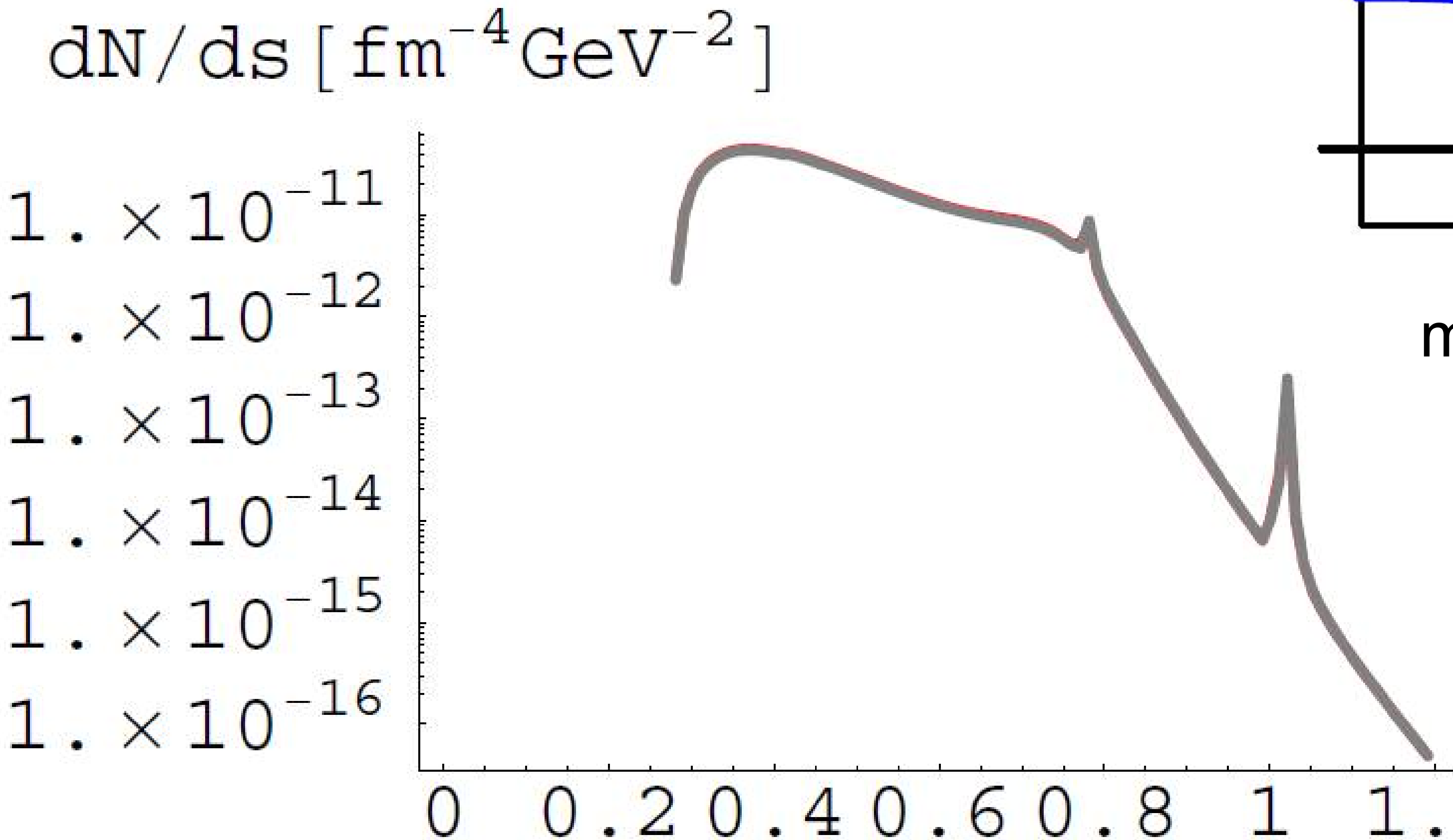
Spectral function at T = 50 MeV

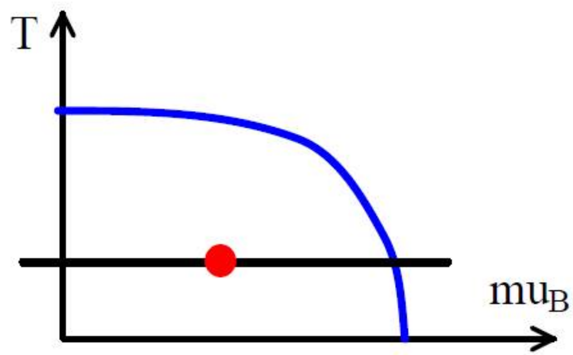


(top) chiral restoration (bottom) no restoration

--- longitudinal --- transverse --- average

Dilepton rates at T = 50 MeV

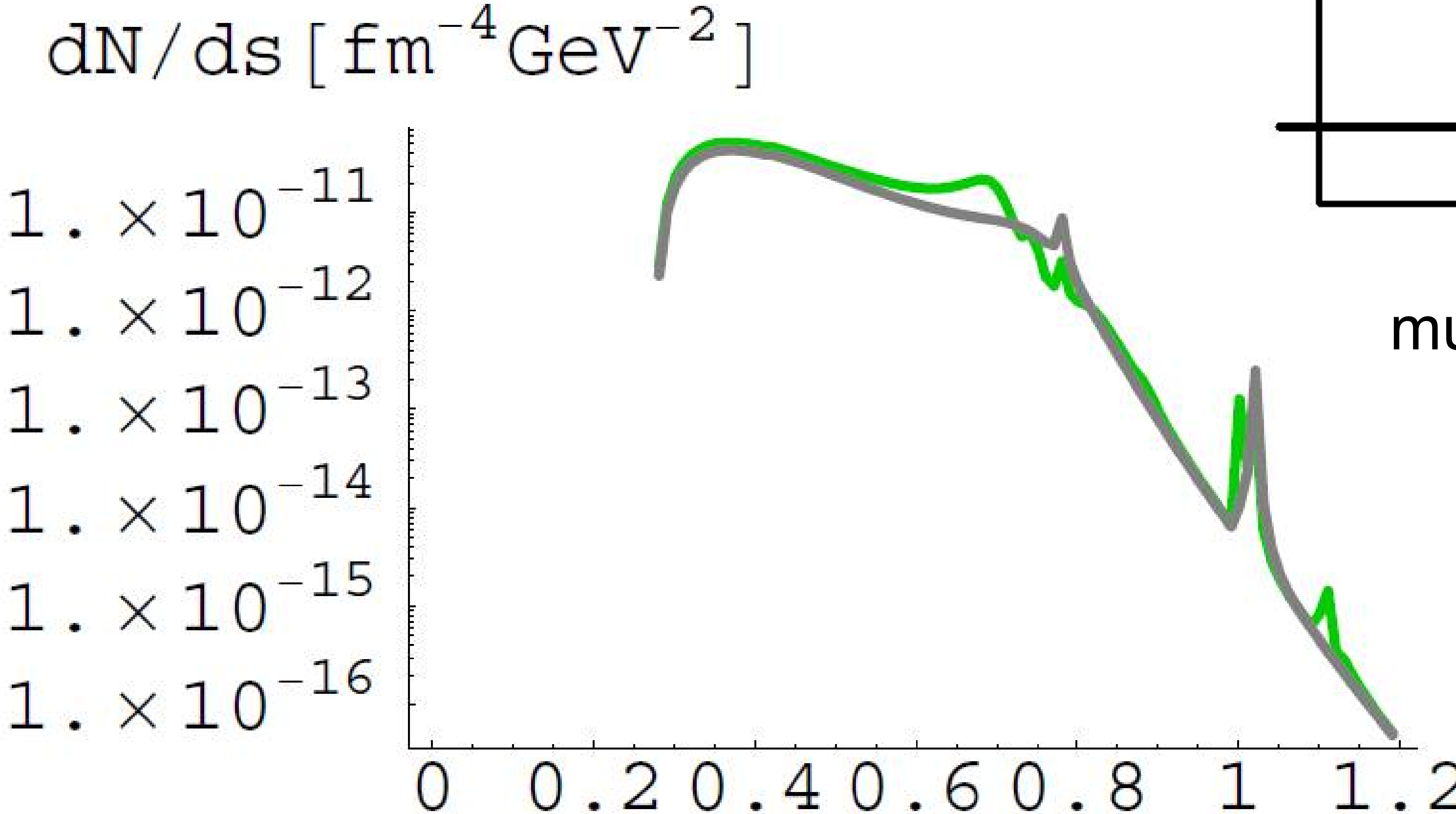


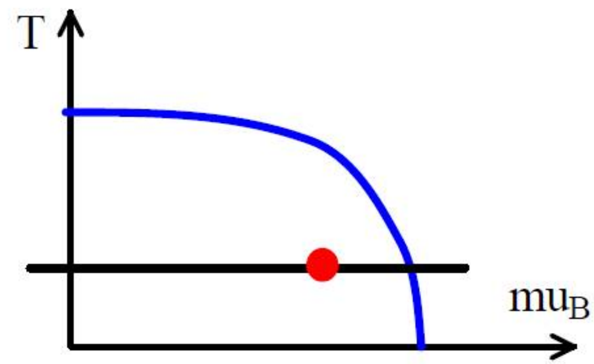


muB = 0.7/GeV

ref. constant masses, no mixing

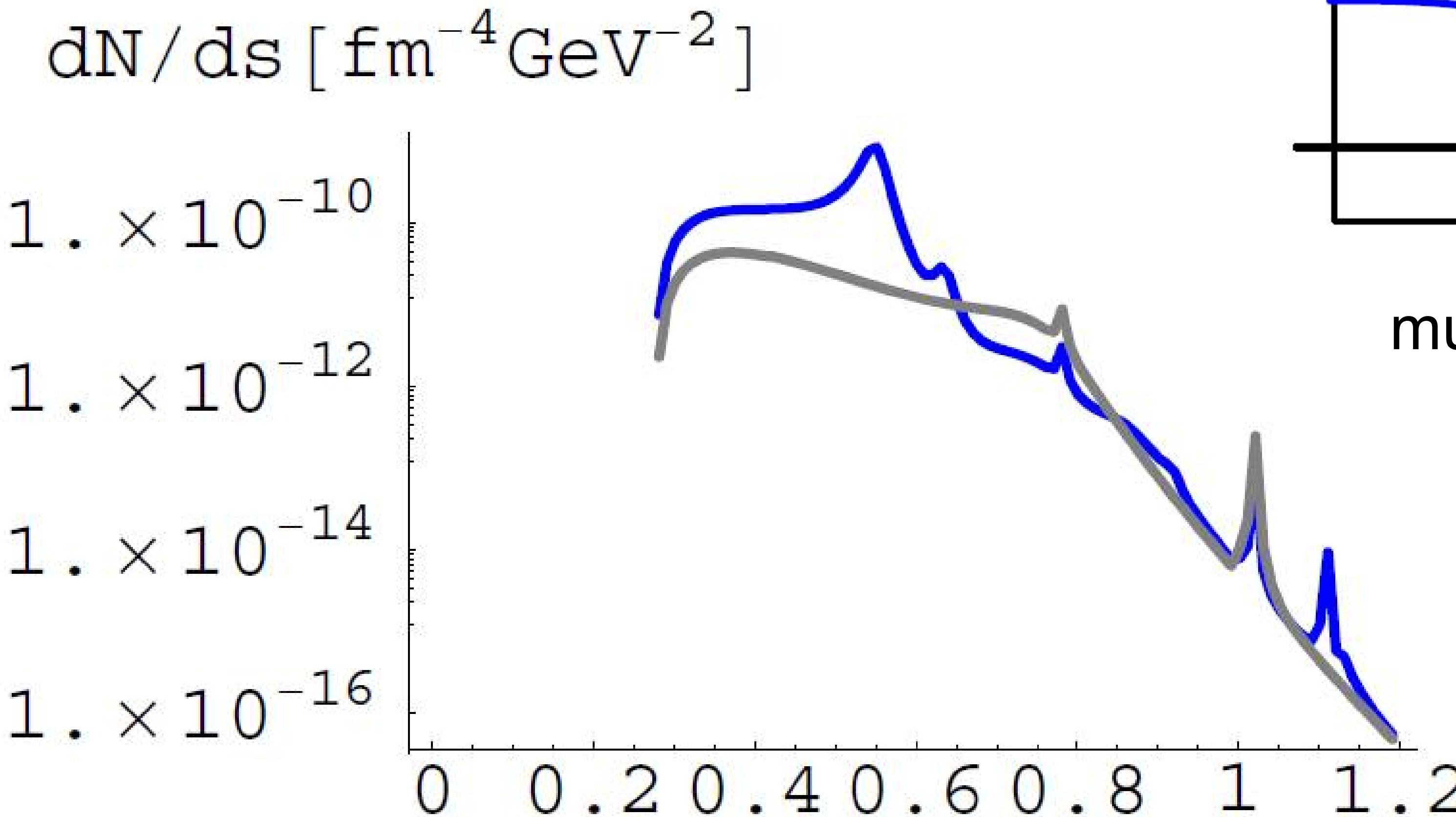
Dilepton rates at T =50 MeV

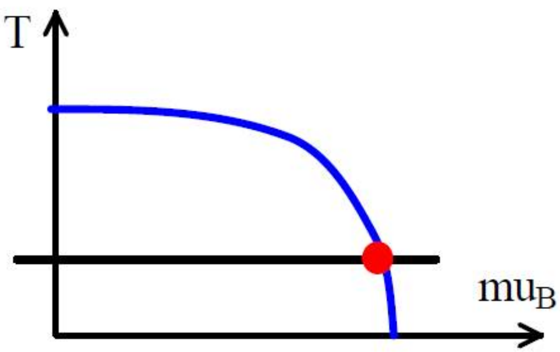




muB = 1.0/GeV

Dilepton rates at T =50 MeV





muB = 1.4/GeV

Summary

- Parity doubling of vector mesons
  - Chiral mixing: temp.-induced vs. density-induced

    (decrease) (increase)

    [Harada, CS, Weise ('08)]

- Chiral symmetry restoration
  - ρ , ω sector: enhancement below vac mass, screened by many-body effects?
  - ϕ sector: peak above mϕ due to the mixing, another peak below mϕ if not too close to CSR