Role of axialvector mesons near the chiral phase transition

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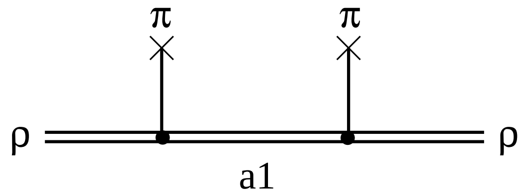
references:

- Harada and Sasaki, Phys. Rev. D **73**, 036001 (2006).
- Harada, Sasaki and Weise, arXiv:0805.4792 [hep-ph];
  arXiv:0807.1417 [hep-ph], accepted for publication in Phys. Rev. D.

Chiral symmetry restoration: role of a_1

- V-A mixing in matter through thermal pions:

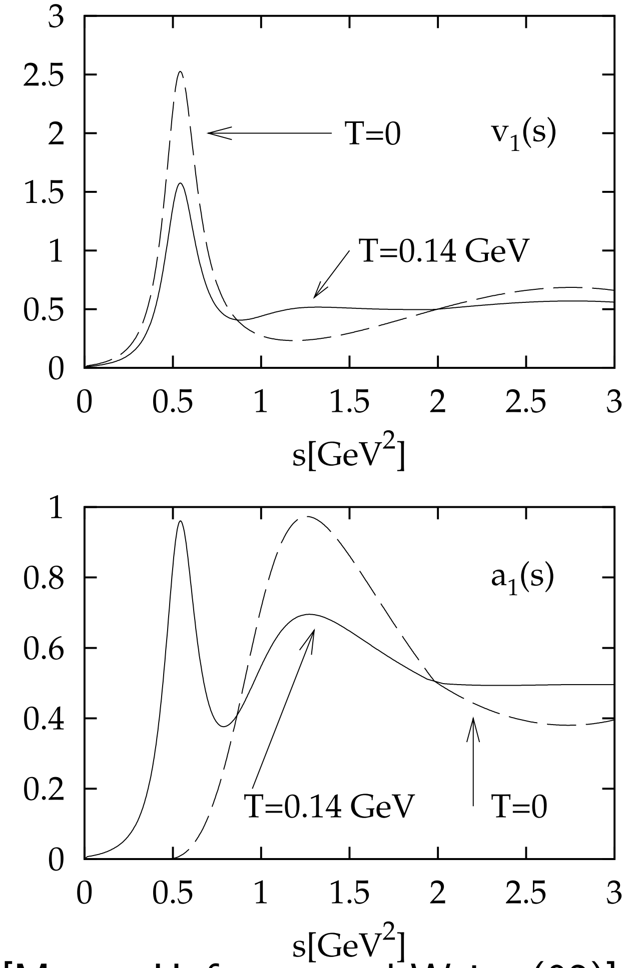


- at low temperature $T \ll m_\pi$:

  only pions are thermally activated.
  a low-energy "theorem" as

$$G_V^{\mu\nu}(T) = (1-\epsilon) G_V^{\mu\nu}(0) + \epsilon\, G_A^{\mu\nu}(0)$$
$$G_A^{\mu\nu}(T) = (1-\epsilon) G_A^{\mu\nu}(0) + \epsilon\, G_V^{\mu\nu}(0)$$
$$\epsilon = \frac{T^2}{6F_\pi^2}, \quad G_{V,A}: \text{ current correlators}$$

[Dey, Eletsky and Ioffe (90)]



[Marco, Hofmann and Weise (02)]

- chiral symmetry restoration
  - "standard" picture: ρ and a_1 chiral partners
    $\Rightarrow$ degenerate masses $m_{a_1} - m_\rho \to 0$
  - $G_V - G_A \to 0$ at $T \to T_c$ in any case
  - maximal mixing $\epsilon = \frac{1}{2}$
    $\Rightarrow$ $G_A = G_V = \frac{1}{2}\left(G_V^{(\mathrm{vac})} + G_A^{(\mathrm{vac})}\right)$
    $\Rightarrow$ chiral sym. restoration? no a_1 modification?
- go beyond
  low-energy limit, other hadrons than pions, higher temperature
- this work
  the first systematic study within an effective field theory

An effective field theory for a π-ρ-a_1 system

- generalized hidden local symmetry (GHLS)

  [Bando, Kugo, Yamawaki (85,88); Bando, Fujiwara, Yamawaki (88); Kaiser, Meissner (90)]

  – an extention of non-linear chiral Lagrangian

  – ρ, a_1 introduced as gauge bosons of the redundant gauge symmetry

- chiral perturbation theory with GHLS [Harada and Sasaki (06)]

  – systematics: order-by-order renormalization

  – Weinberg 1st & 2nd sum rules

$$F_\pi^2 + F_{a_1}^2 = F_\rho^2 \,, \quad F_{a_1}^2 M_{a_1}^2 = F_\rho^2 M_\rho^2$$

  are stable against quantum corrections.

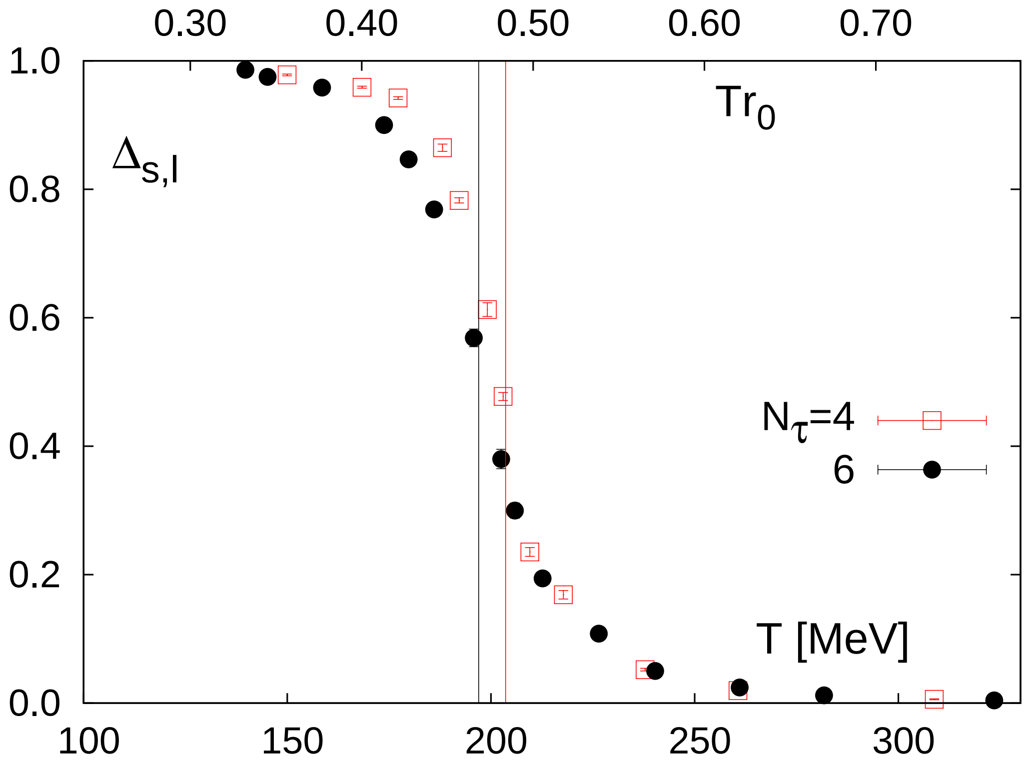
- description of chiral sym. restoration

$$G_A - G_V \to 0 \quad \Rightarrow \quad M_{a_1} - M_\rho \to 0$$

just a parameter $\delta M = M_{a_1} - M_\rho$: how δM goes to zero?

Turning on/off partial restoration: flash temperature

- lattice QCD calculation with almost physical quark masses ($m_\pi \simeq 220$ MeV) [M. Cheng *et al.* (08)]

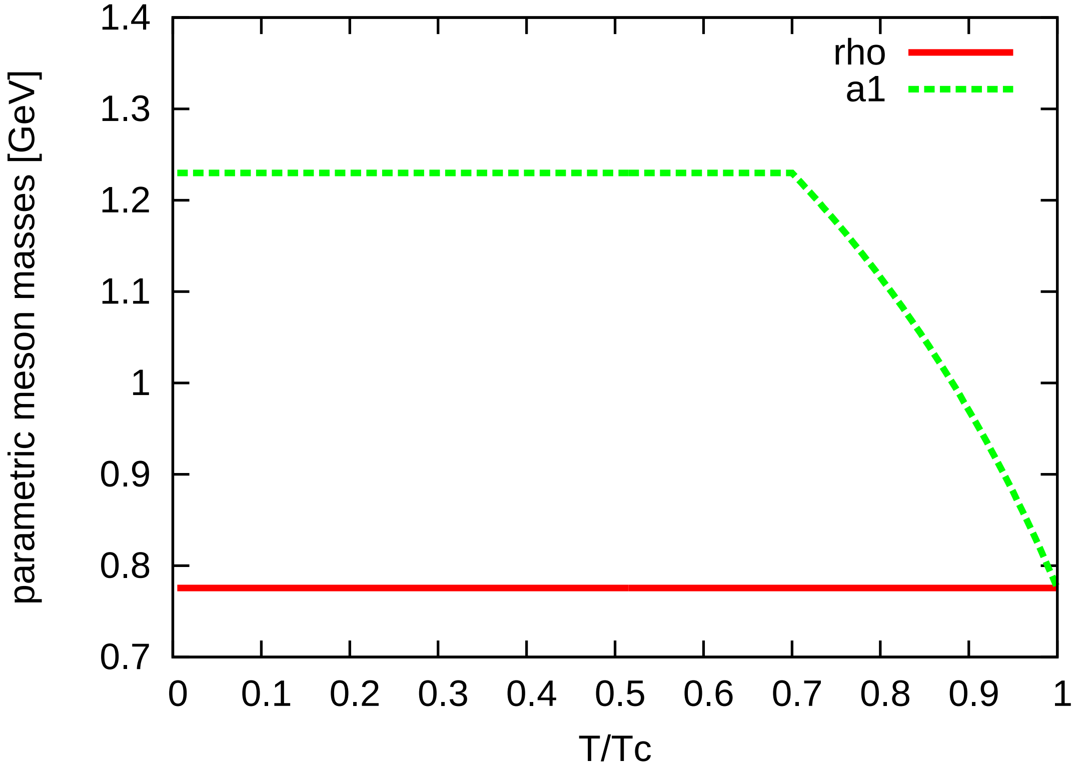


- quark condensate starts to melt at $T \simeq 140$ MeV
  $\Rightarrow$ introduce the flash temperature $T_f = 140$ MeV:
  partial chiral sym. restoration sets in at T_f.

- assume ρ *bare* mass is independent of T.
- take a simple T-dep. of $M_{a_1}^2 - M_\rho^2 = \delta M^2(T) = c(T) g^2 F^2$ as

$$c(T) = c(T=0)\,\Theta(T_f - T) + c(T=0)\,\Theta(T - T_f)\frac{T_c^2 - T^2}{T_c^2 - T_f^2}$$

- ρ and a_1 *bare* masses at finite T: ($T_f = 140$ MeV & $T_c = 200$ MeV)

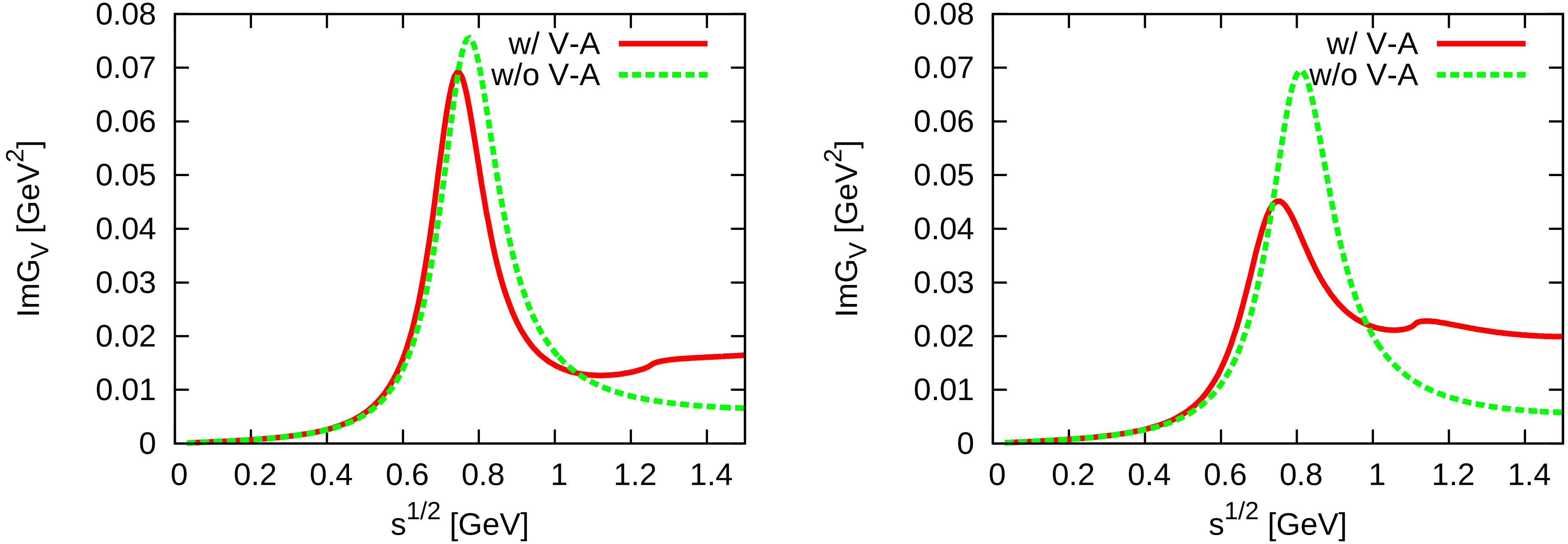


- pion decay constant $F_\pi^2 \propto c(T) F^2 \to 0$ at T_c

V-A mixing in hot matter: vector spectral function

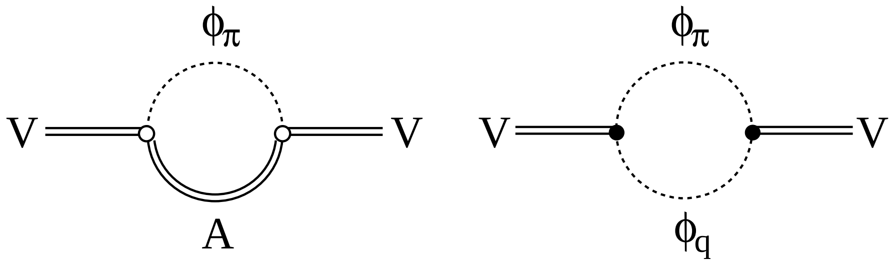
- vector spectral function in the chiral limit

below T_f above T_f



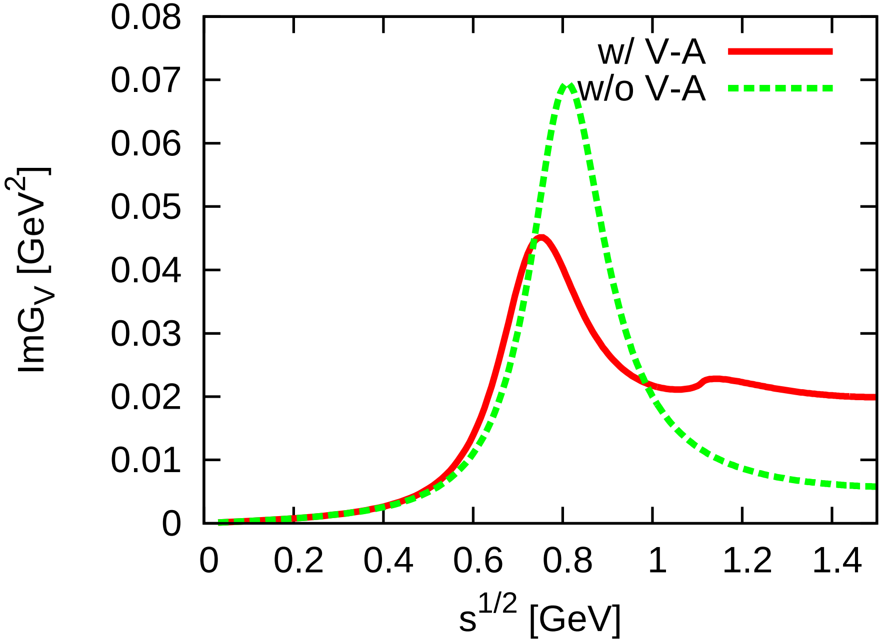
– effect of a_1 meson becomes significant above T_f

– 2 bumps appear through V-A mixing

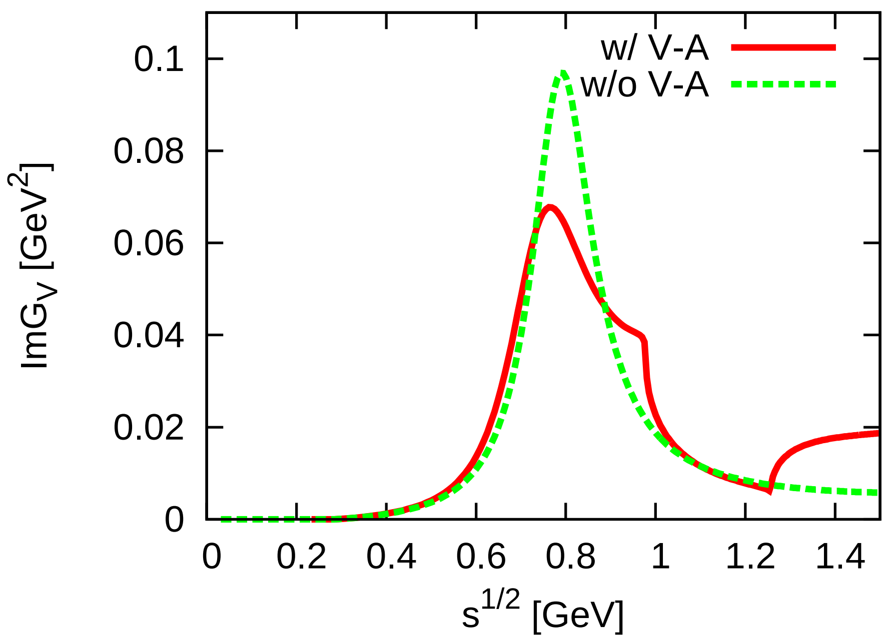


- vector spectral function: m_π dependence

$m_\pi = 0$



$m_\pi = 140$ MeV

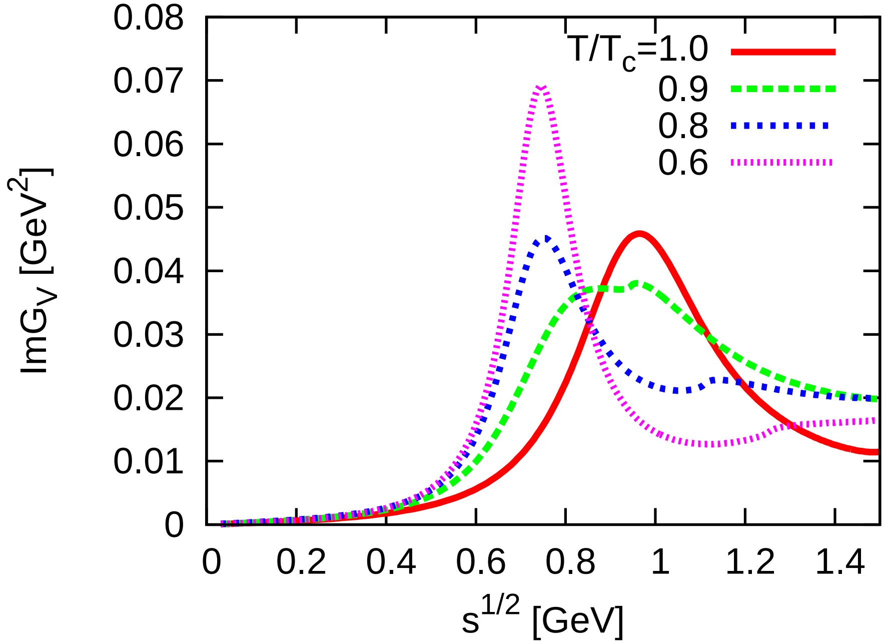


– 2 processes kinematically allowed: $\rho + \pi \to a_1$ and $\rho \to a_1 + \pi$

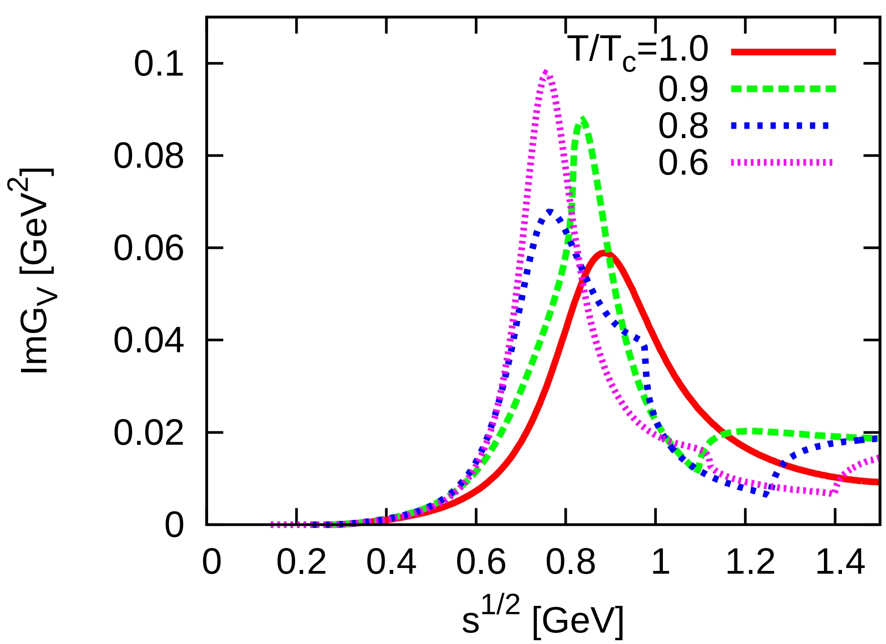
– finite m_π: $\sqrt{s} = m_{a_1} - m_\pi$ and $\sqrt{s} = m_{a_1} + m_\pi$

- vector spectral function: T dependence

$m_\pi = 0$



$m_\pi = 140$ MeV



– 2 bumps on top at T_c

– masses of chiral partners near T_c:

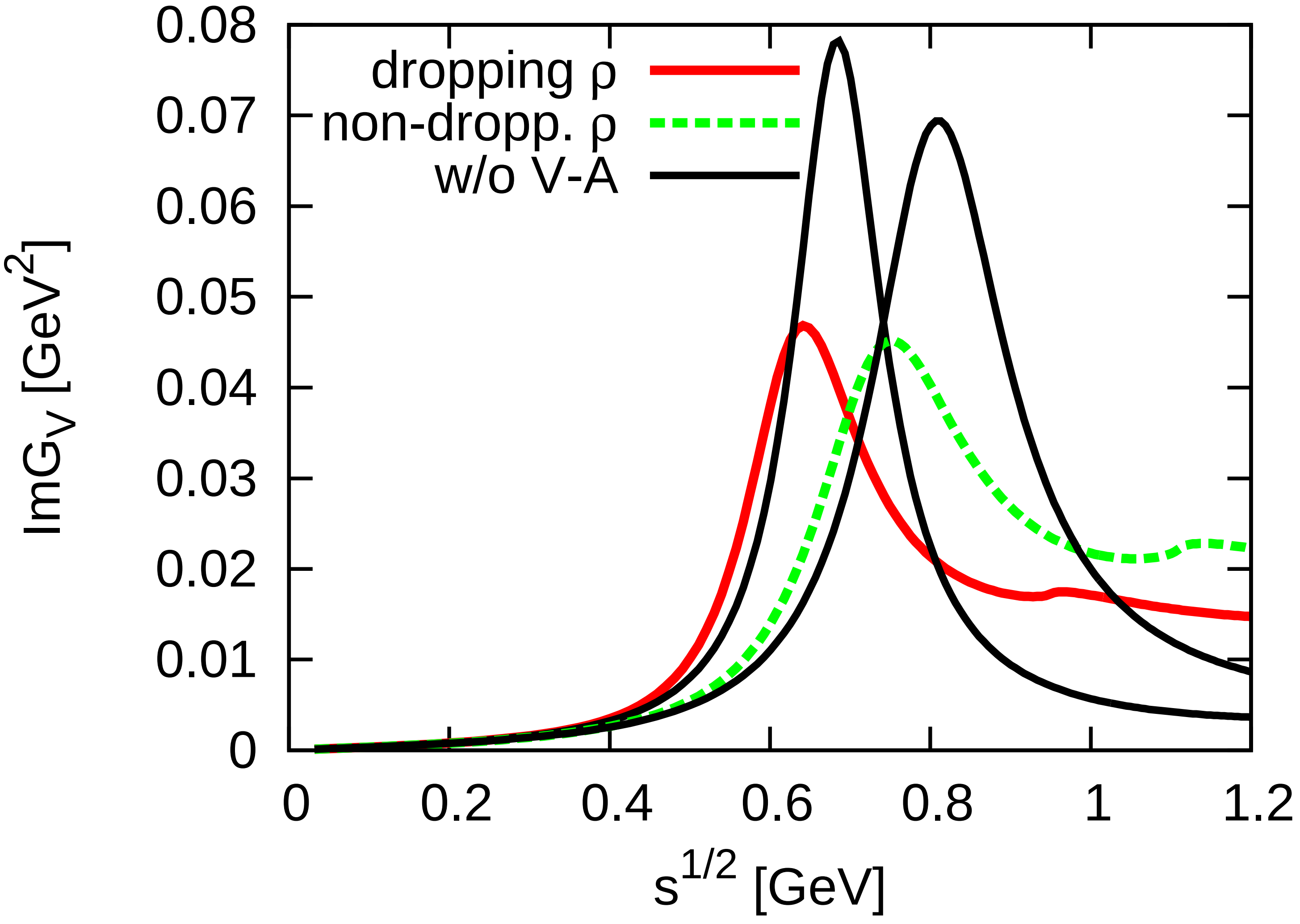
$$M_{a_1} - M_\rho \simeq \sqrt{h_A - h_V}\, m_\pi \simeq 3\,\text{MeV}$$

– unchanged by $\bar{q}q$ scalar mode

a linearized hidden-local-symmetric model [M. Harada, C. S., W. Weise (2008)]

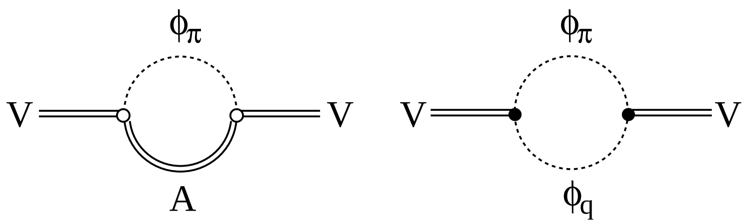
A case study: dropping vs. non-dropping ρ mass

- non-dropping vs. dropping *bare* ρ mass: V-A mixing more significant



Conclusions

- a systematic study of chiral symmetry restoration (d.o.f.: π, ρ, a_1)
  - vanishing order parameter: $F_\pi^2 \propto c(T)$
  - degenerate masses of chiral partners: $\delta M^2 \propto c(T)$
- single unified bump at T_c
  $\Leftrightarrow$ 2 bumps from a naive extrapolation of the mixing theorem
- ρ-a_1 masses well degenerate near T_c even for $m_\pi = 140$ MeV
  - suppression of a_1-ρ-π coupling near T_c: $g_{a_1\rho\pi} \sim 0.06\, m_\pi$



  - pion loop contribution more and more important above T_f

$$\mathrm{Im}\Pi_V(T) \sim \left(1 + \frac{M_\rho^2}{M_{a_1}^2(T)}\right) F(m_\pi, m_\pi; T)$$

- application to dilepton production, signature of χ-sym. restoration