In-medium modification of meson properties in a chiral quark model

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Outline

$U(3) \times U(3)$ Nambu–Jona-Lasinio model

$$\begin{aligned}\mathcal{L} \quad &= \bar{q}(i\hat{\partial} - m^0)q + G_1 \sum_{i=0}^{8} \left[(\bar{q}\lambda_i q)^2 + (\bar{q} i\gamma_5 \lambda_i q)^2\right] \\ &-G_2 \sum_{i=0}^{8} \left[(\bar{q}\gamma_\mu \lambda_i q)^2 + (\bar{q}\gamma_5\gamma_\mu \lambda_i q)^2\right] \\ &-K\left\{\det[\bar{q}(1+\gamma_5)q] + \det[\bar{q}(1-\gamma_5)q]\right\}.\end{aligned}$$

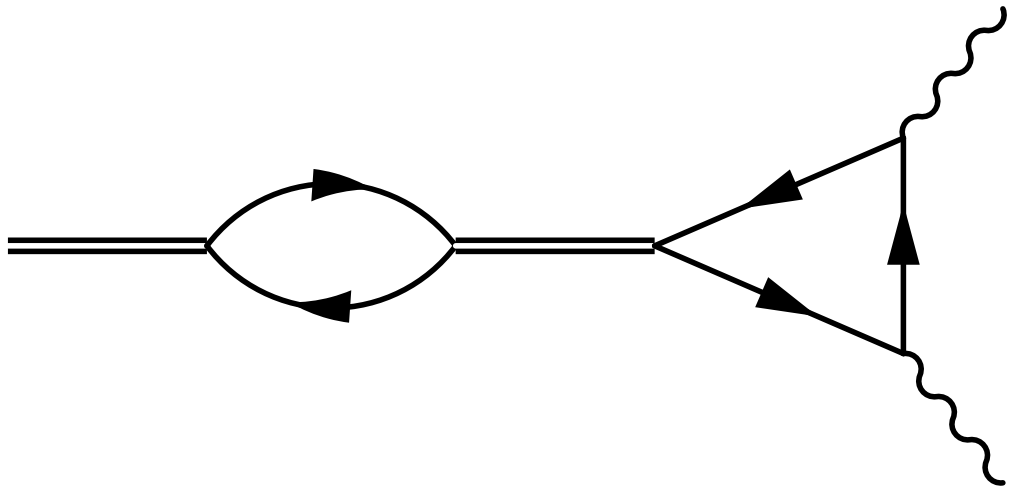
G_1 and G_2 are the four-quark interaction constants in the scalar–pseudoscalar and vector–axial-vector channels; K is the six-quark interaction constant.

Model parameters

The model parameters in vacuum are fixed in a way that allows one to reproduce the masses of π, K and ρ mesons, the pion weak-decay constant, the strong decay width of the ρ-meson and the mass difference of η and η' mesons.

- $m_u = 280$ MeV
- $m_s = 416$ MeV
- $G_1 = 3.2$ GeV^{-2}
- $G_2 = 16$ GeV^{-2}
- $K = 4.6$ GeV^{-5}
- $\Lambda_3 = 1.03$ GeV

Vector-meson decays



$$A^{\alpha\mu\nu}_{V\to\gamma\gamma} = J^{\alpha}_{V\to S} D_S T^{\mu\nu}_{S\to\gamma\gamma},$$

- scalar-vector transition
- scalar meson propagator
- decay of the scalar meson to two photons

The decay $\rho \to \gamma\gamma$

$$A^{\alpha\mu\nu}_{\rho\to\gamma\gamma} = J^{\alpha}_{\rho\to a_0} D_{a_0} T^{\mu\nu}_{a_0\to\gamma\gamma},$$

a_0 propagator

$$D_{a_0} = (M^2_{a_0} - M^2_{\rho} - i\Gamma_{a_0}(M_\rho) M_{a_0})^{-1}.$$

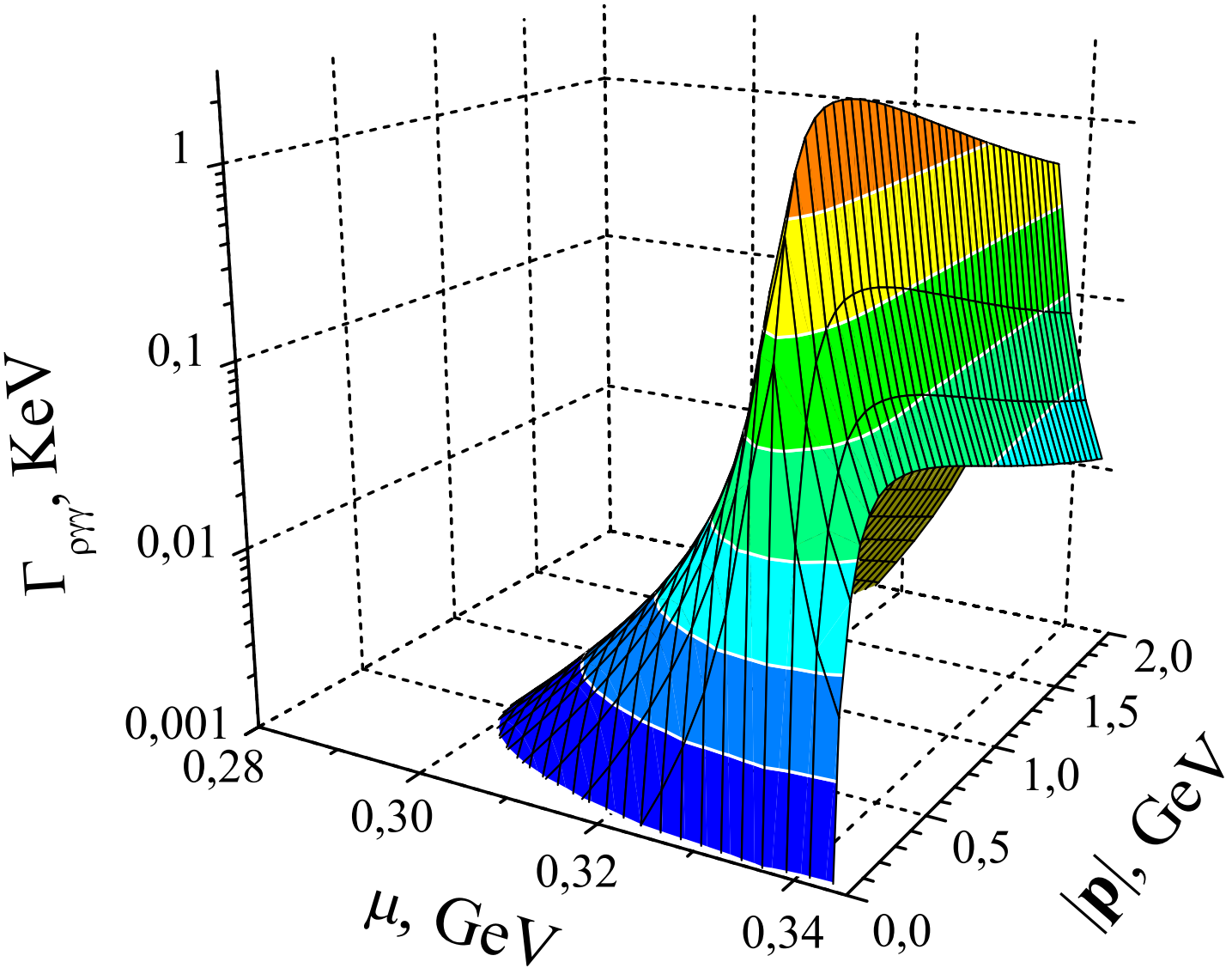
$$M^{\rm NJL}_{a_0} \approx 800\,{\rm MeV}$$

$$M^{*\,2}_{a_0} = M^2_{a_0} + \Delta.$$

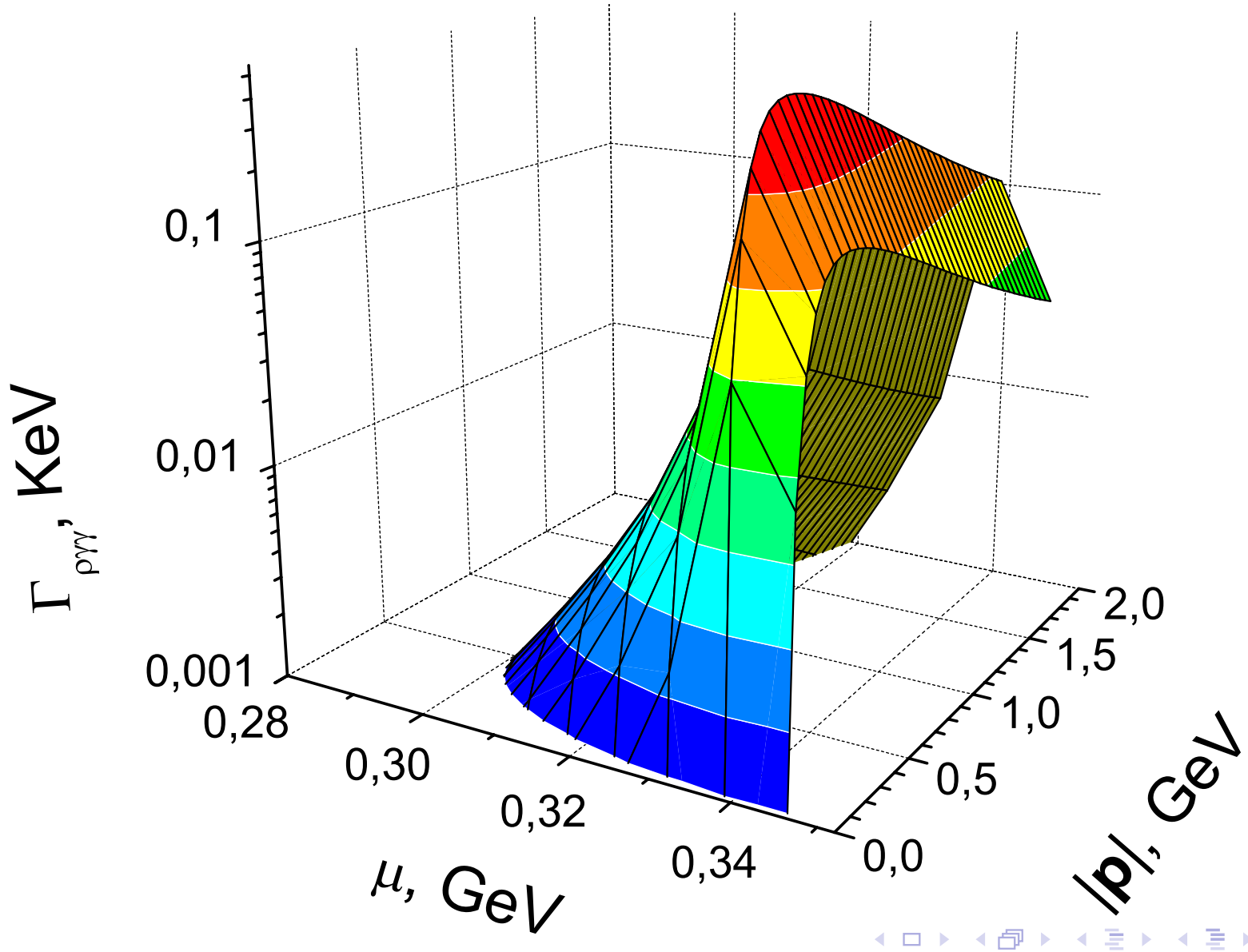
- $\Delta_u = 4m_u^2$
- $\Delta_{us} = 2.75 m_u m_s$

$$\Gamma_{a_0}(M_\rho) \quad \approx \quad \Gamma_{a_0\eta\pi}(M_\rho) = \frac{g^2_{a_0\eta\pi}}{16\pi M_\rho} \sqrt{1 - \left[\frac{M_\eta + M_\pi}{M_\rho}\right]^2} \sqrt{1 - \left[\frac{M_\eta - M_\pi}{M_\rho}\right]^2}$$

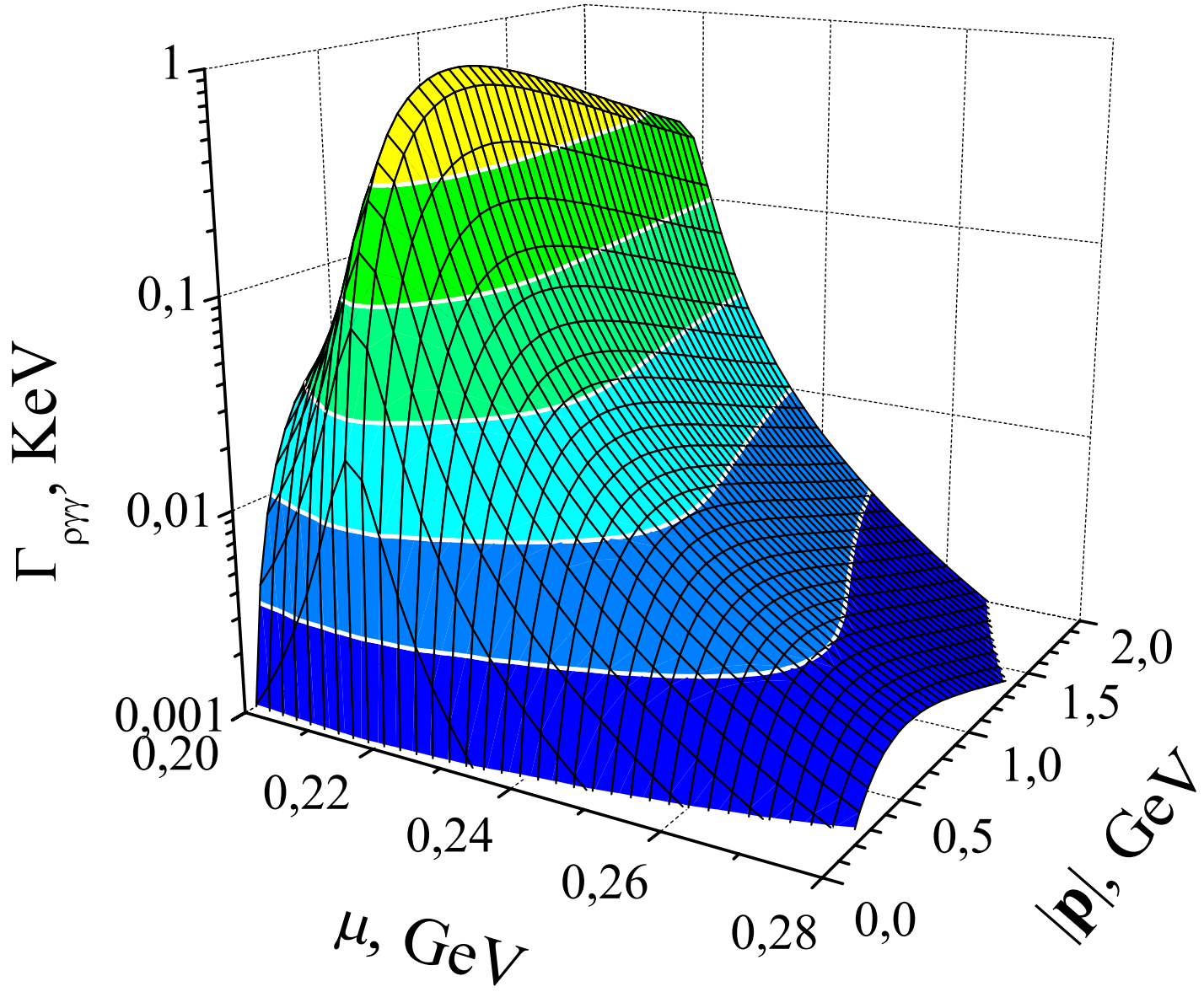
Two-photon decay width of ρ-meson with the a_0 mass corrected by $\Delta = \Delta_u$ as a function of μ and $|\mathbf{p}|$ for $T = 20$ MeV.



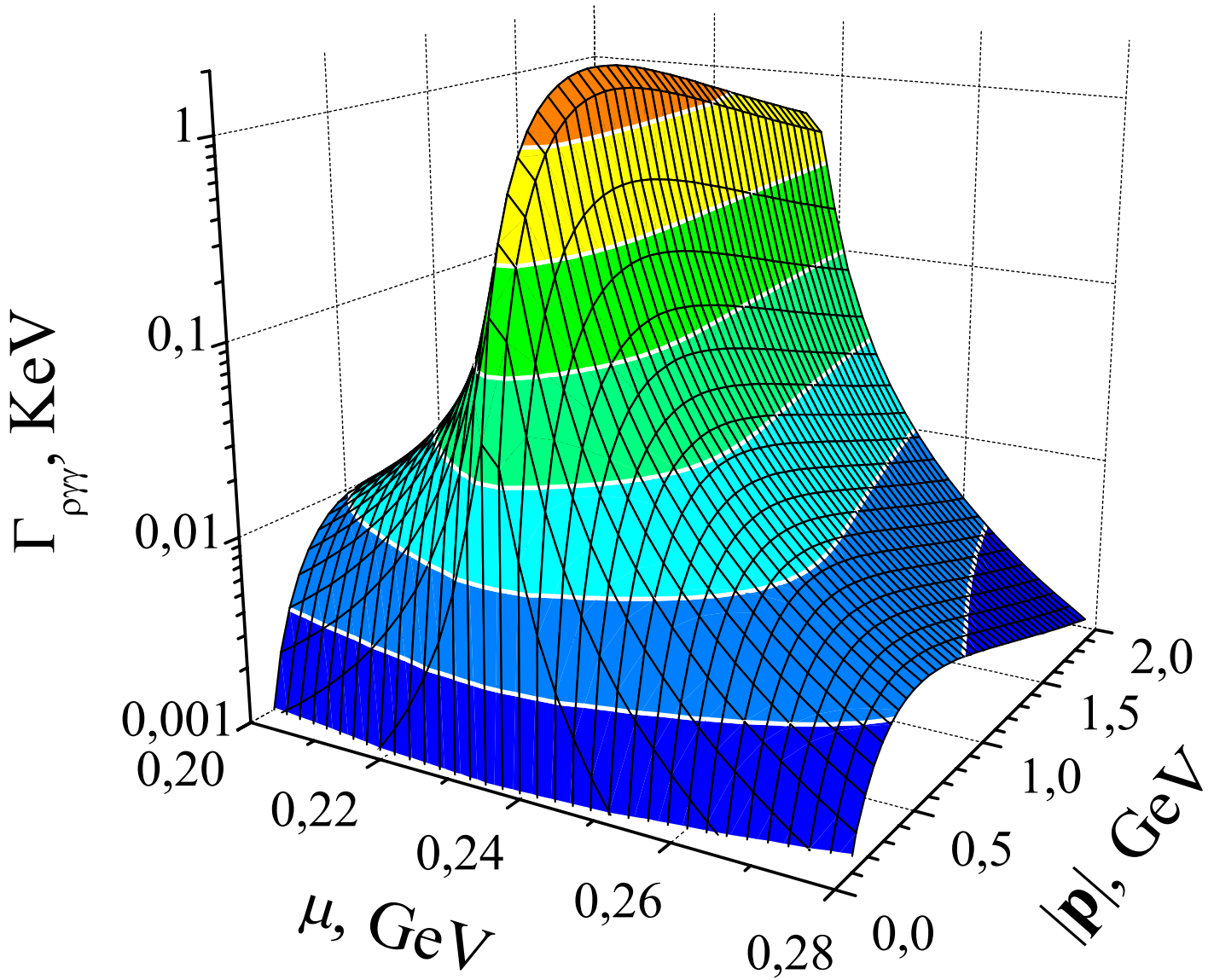
Two-photon decay width of the ρ-meson with the a_0 mass corrected by $\Delta = \Delta_{us}$ as a function of μ and $|\mathbf{p}|$ for $T = 20$ MeV.



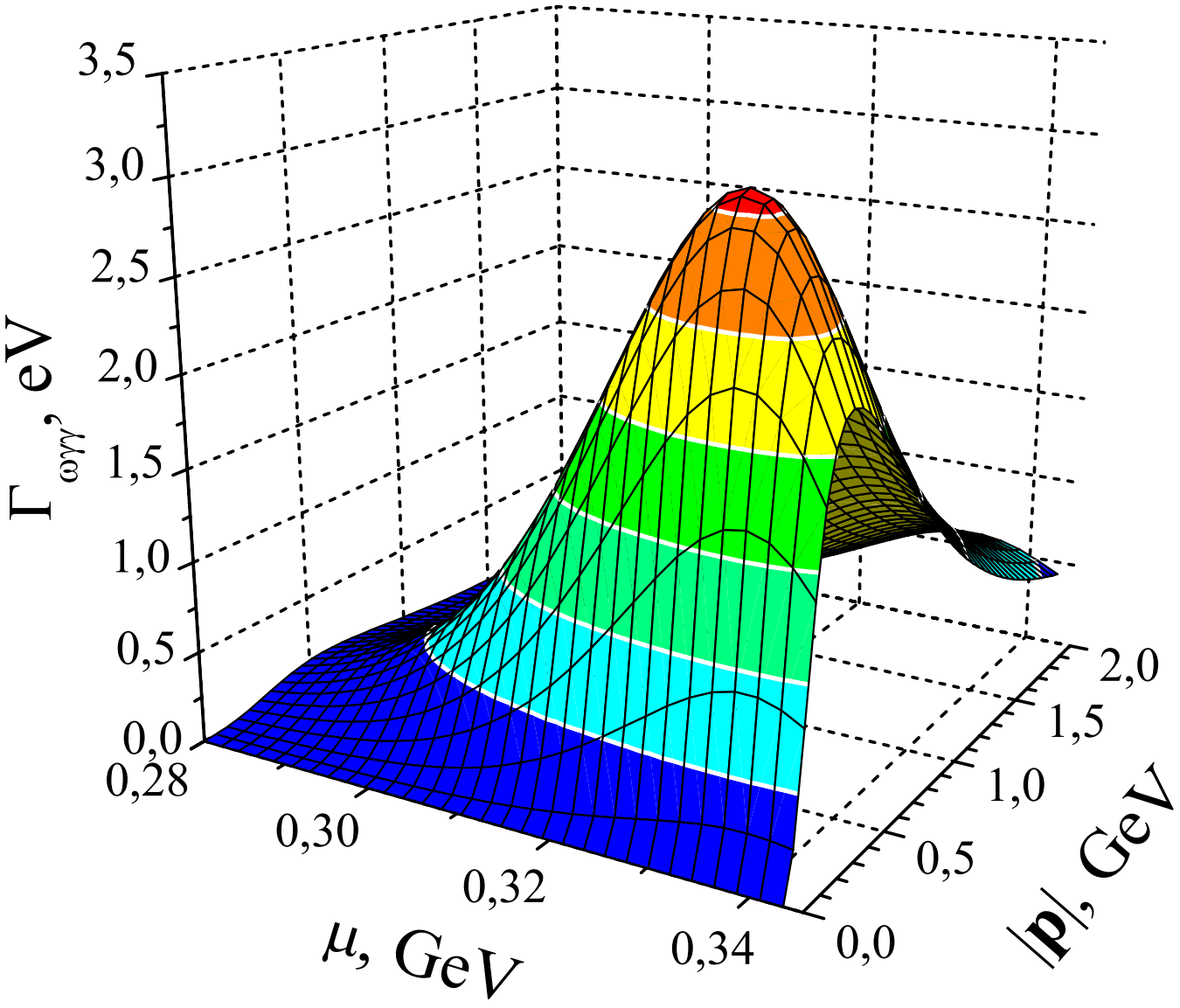
Two-photon decay width of the ρ-meson with the a_0 mass corrected by $\Delta = \Delta_u$ as a function of μ and $|\mathbf{p}|$ for $T = 120$ MeV.



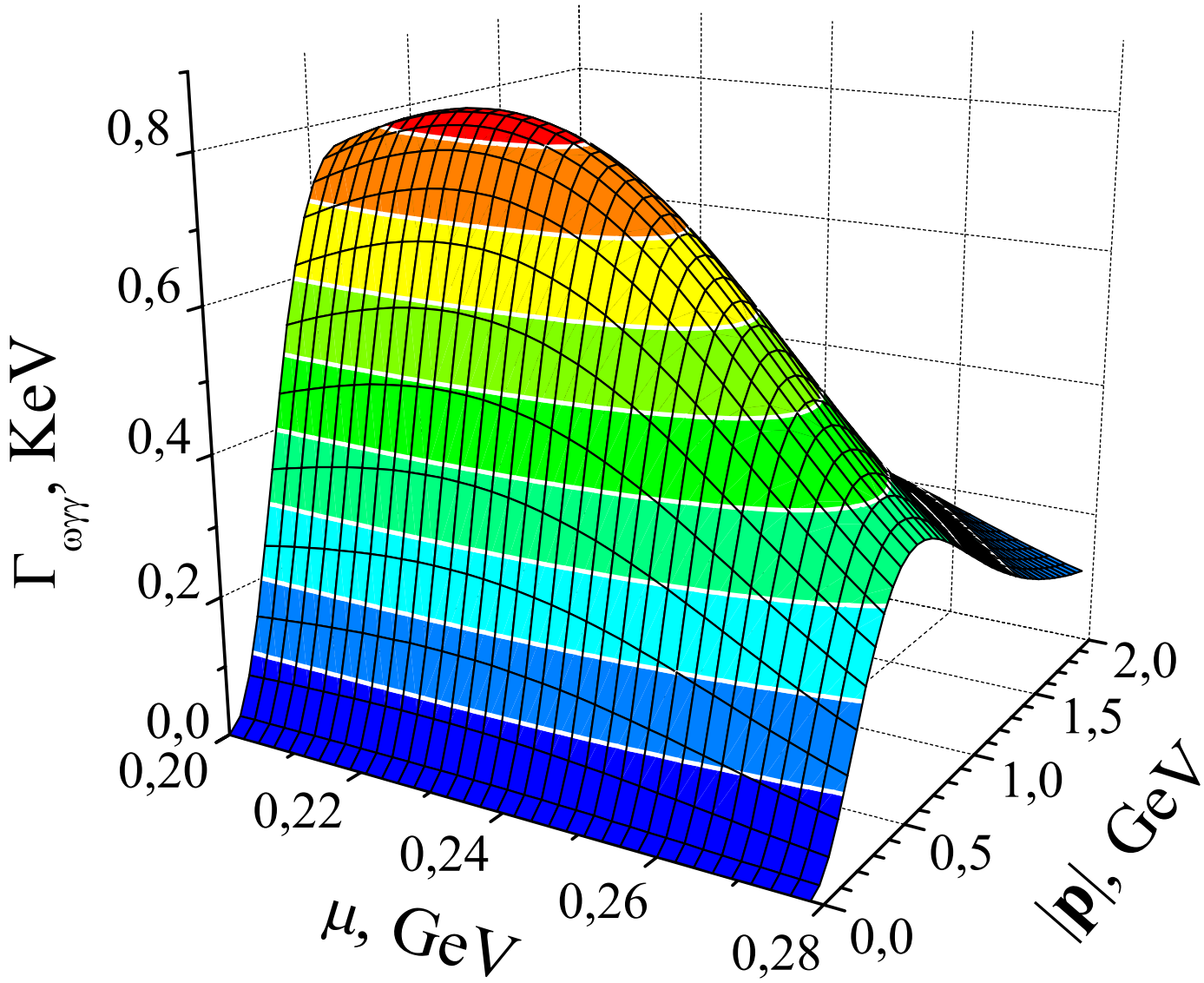
Two-photon decay width of the ρ-meson with the a_0 mass corrected by $\Delta = \Delta_{us}$ as a function of μ and $|\mathbf{p}|$ for $T = 120$ MeV.



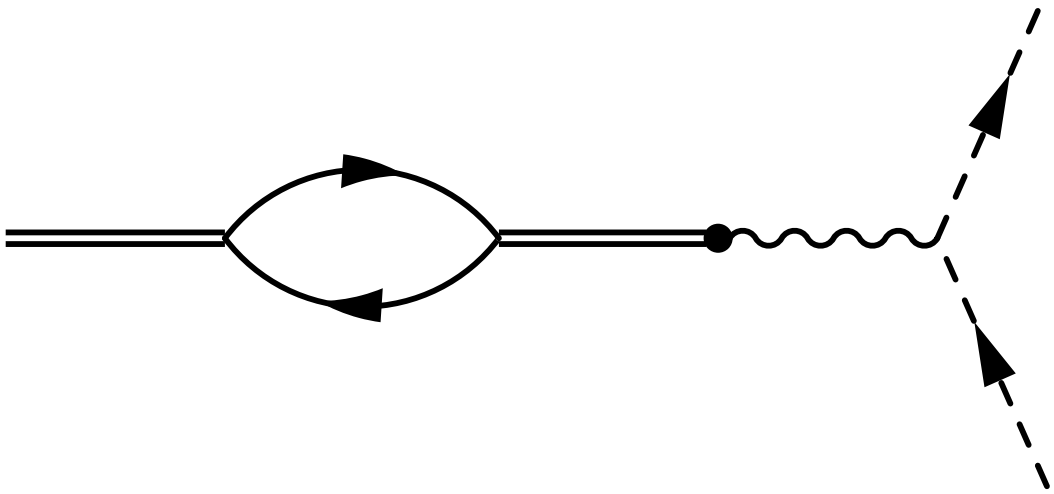
Two-photon decay width of the ω-meson as a function of μ and $|\mathbf{p}|$ for $T = 20$.



Two-photon decay width of the ω-meson as a function of μ and $|\mathbf{p}|$ for $T = 120$ MeV.



Dilepton decays of scalar meson in medium via scalar-vector mixing



$\sigma \to e^+e^-$

Numerically the decay $\sigma \to e^+e^-$ reaches 1.5 keV in maximum.

$a_0 \to e^+e^-$

Due to the mass degeneration of ρ and a_0 near the phase transition, a resonant enhancement is to be observed in the decay $a_0 \to e^+e^-$. The rate of the decay $a_0 \to e^+e^-$ turns to be larger almost by an order (~ 10 keV at the maximum), comparing to the decay $\sigma \to e^+e^-$.

Summary

- Two-photon decays of vector mesons and dilepton decays of scalar mesons are forbidden in free space but in medium they give an additional contribution to the corresponding two-photon and dilepton spectra in heavy-ion collisions. These decays are determined by scalar-vector mixing which strongly depend on temperature, chemical potential and on the momentum of the decaying particle in the medium.
- The rate of each decay vanishes in free space and is maximal near the transition from the hadron phase to the phase with restored chiral symmetry. The conditions in which the effect is noticeable correspond to a wide range in the phase diagram.
- Additional enhancement is produced by the resonant effect if the ρ in involved.

Two-photon decays of scalar and pseudoscalar mesons in vacuum

Particle	Mass, MeV	$\Gamma_{\gamma\gamma}$, keV
π^0	134.9766 ± 0.0006	$(7.8 \pm 0.5) \cdot 10^{-3}$
η	547.75 ± 0.12	1.29 ± 0.07
η'	957.78 ± 0.14	4.29 ± 0.15
σ	$400 - 1200$	~ 1
a_0	984.7 ± 1.2	0.3 ± 0.1
f_0	980 ± 10	$0.39^{+0.1}_{-0.13}$

Meson masses

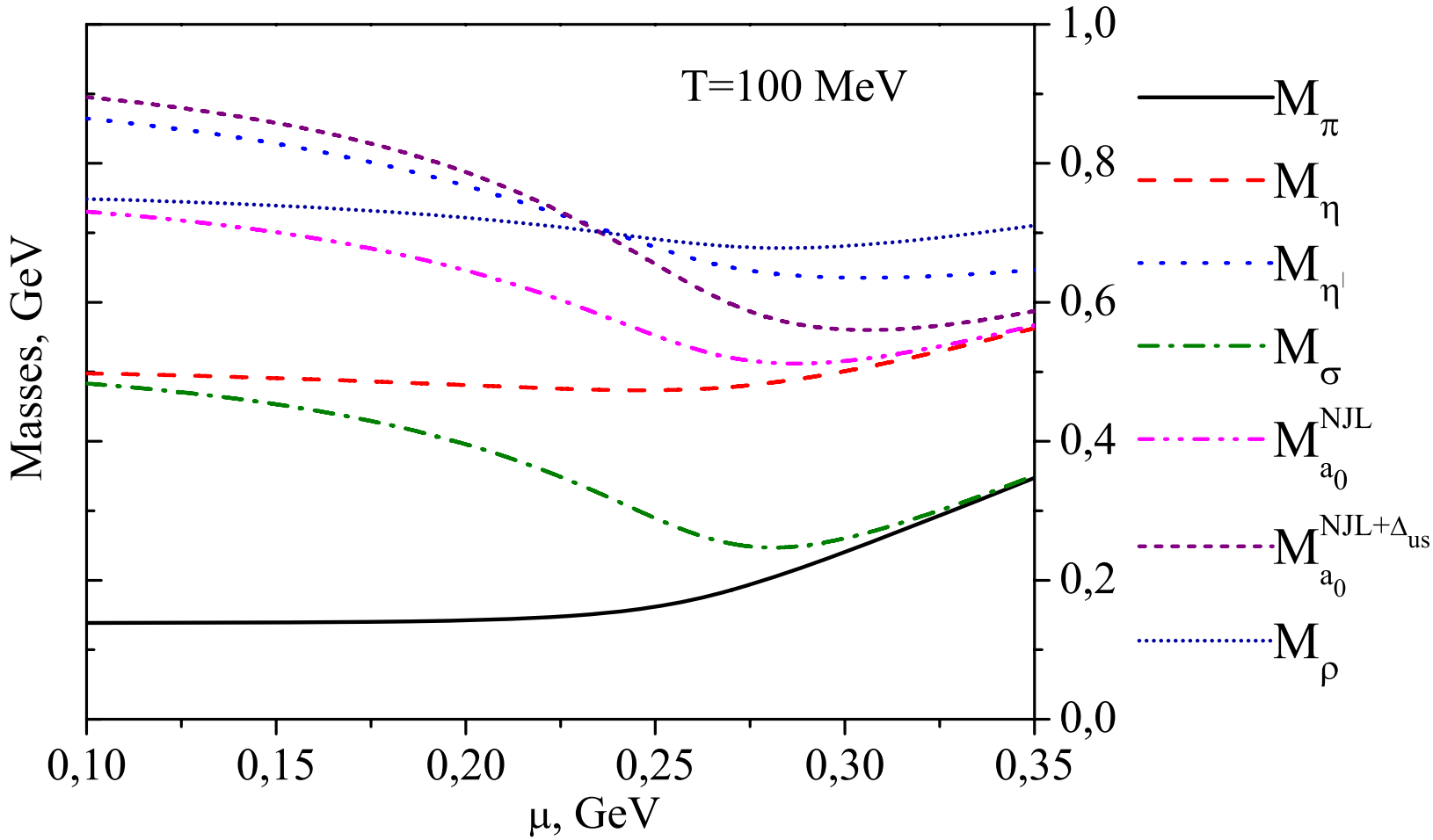
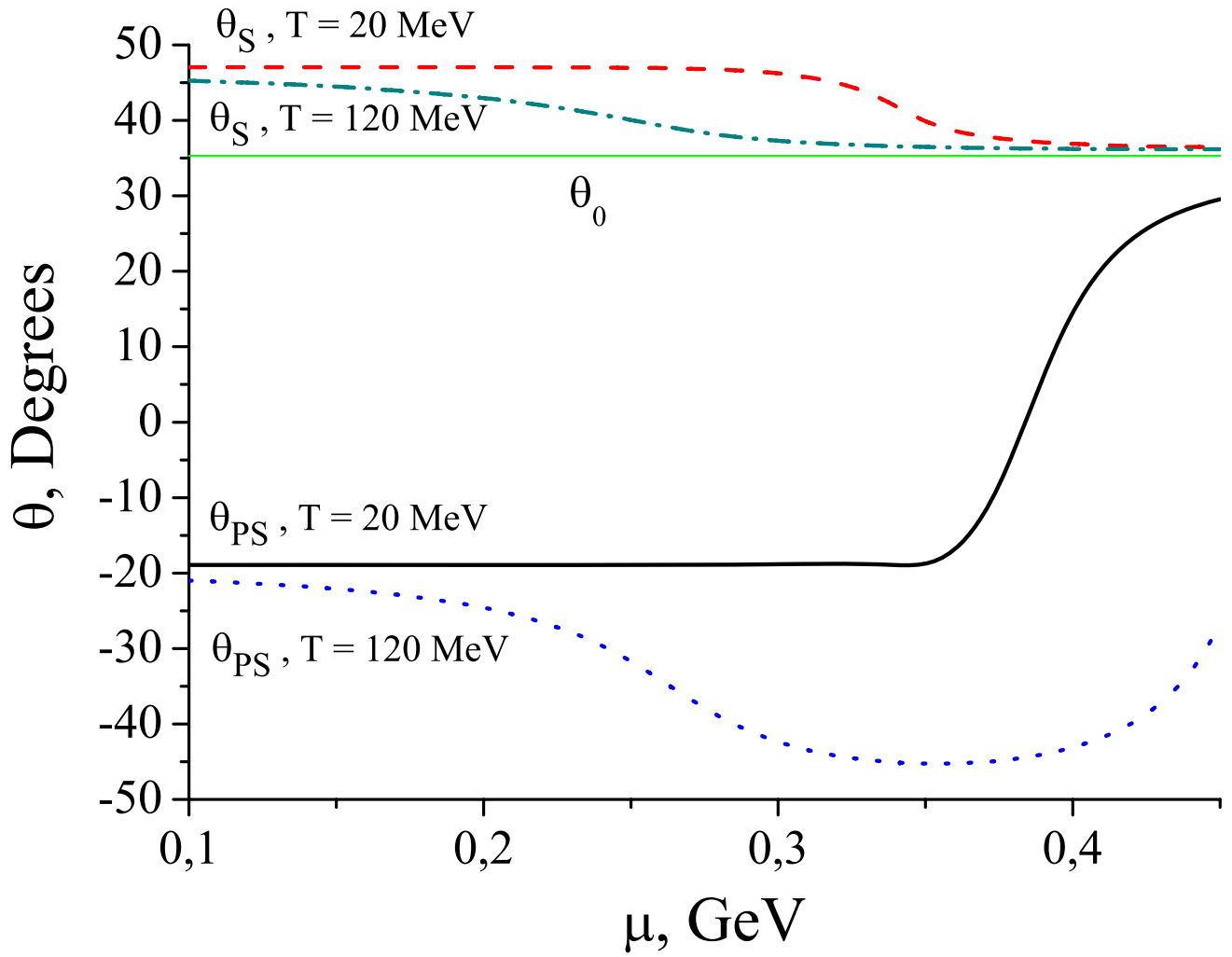


Figure: The masses of π, a_0, σ, ρ, η and η' -mesons as functions of μ at $T = 100$ MeV.

Mixing angles for scalar and pseudoscalar mesons in the NJL model for $T = 20$ MeV and $T = 120$ MeV as functions of chemical potential μ.



The widths of decays $a_0 \to \eta\pi$ and $\sigma \to \pi\pi$ in the NJL model for $T = 20$ MeV as functions of chemical potential μ.