D^* and B^* Mesons in Strange Hadronic Medium at Finite Temperature and Density

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Physics Opportunities at an Electron-Ion Collider(POETIC6)

Outline

- Aim and motivation
- Model used(Chiral Model and QCD Sum rule)
- D mesons in hot strange hadronic matter
- Results
- Summary

Need to study the medium modification of vector D and B mesons ?

➢ To understand the possible outcomes of future experiments

- CBM(Compressed Baryonic Matter)
- PANDA (anti-**P**roton **AN**nihilations at **DA**rmstadt.)

Under the FAIR(Facility of Antiproton and Ion Research) project at GSI, Germany.

Motivation

- Quarkonium suppression (J/psi)
- Bound states of D mesons with nuclei
- Production rate of D and B mesons

Phase Diagram

Hadron gas:

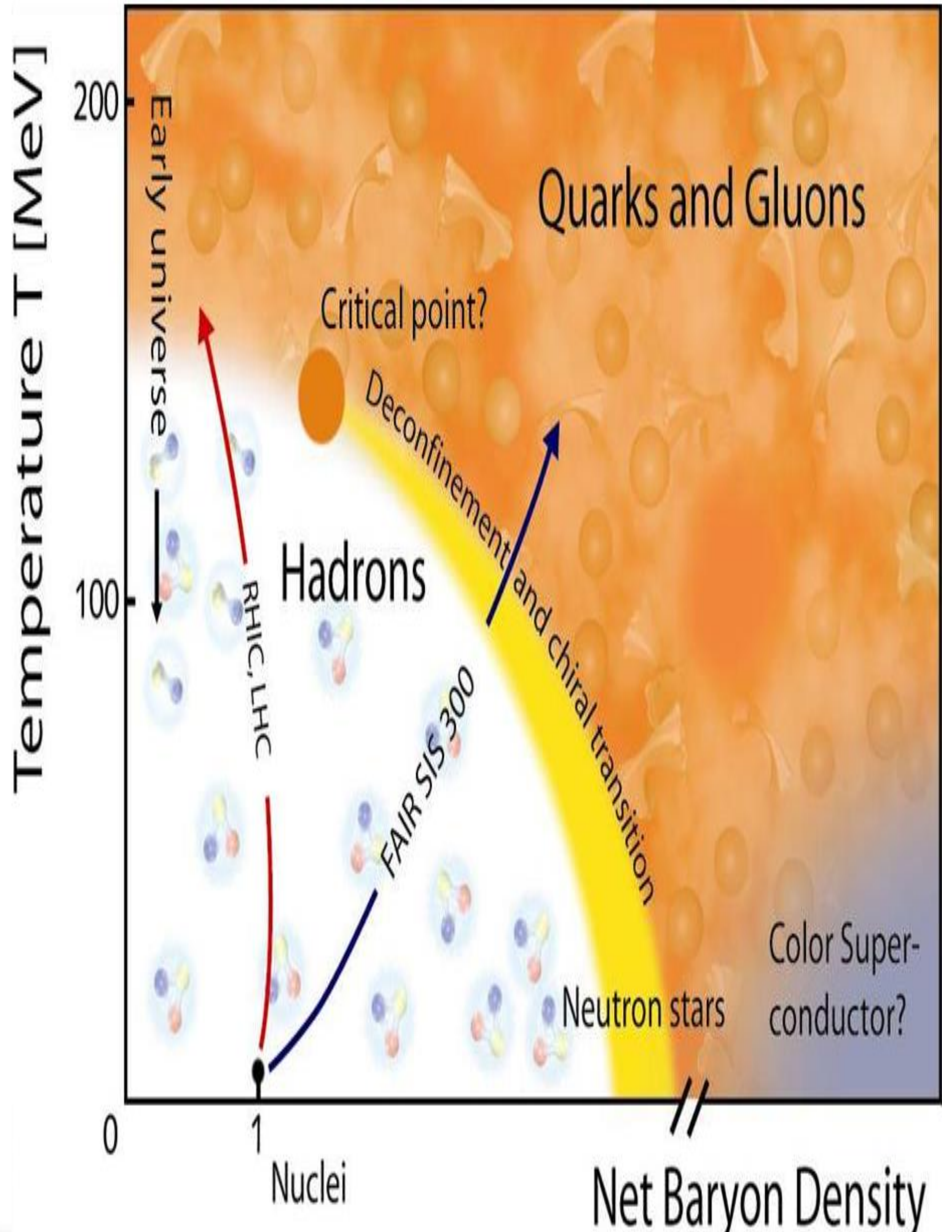
•At Moderate temperatures and densities quarks and gluons are confined

• Chiral symmetry is spontaneously broken

Quark-gluon plasma:

• At very high temperatures and densitie deconfinement of quarks and gluons

• Chiral symmetry is restored



Chiral SU(3) Model

- Chiral symmetry

  Limit of massless quarks i.e. $m_u = m_d = m_s = 0$

  Invariance of QCD Lagrangian under $SU(3)_L \times SU(3)_R$ transformation.

- Explicit symmetry breaking term is used to introduced in mode for masses
- Broken scale invariance, which leads to non zero trace of energy momentum tensor

$$\theta_\mu^\mu = \langle \frac{\beta_{QCD}}{2g} G_{\mu\nu}^a G_a^{\mu\nu} \rangle$$

- Mean-field approximation

Lagrangian Density is given as

Explicit symmetry breaking

Interaction of Vector mesons

Kinetic term

$$\mathcal{L} = \mathcal{L}_{kin} + \sum_{W=X,Y,V,A,u} \mathcal{L}_{BW} + \mathcal{L}_{vec} + \mathcal{L}_0 + \mathcal{L}_{SB}$$

Baryon meson interactions

Meson-meson interactions

Coupled equations of motion of scalar fields derived from effective Lagrangian using mean field approximation :

For sigma field:

$$k_0\chi^2\sigma - 4k_1(\sigma^2+\zeta^2)\sigma - 2k_2(\sigma^3) - 2k_3\chi\sigma\zeta - \frac{d}{3}\chi^4\left(\frac{2}{\sigma}\right) + \left(\frac{\chi}{\chi_0}\right)^2 m_\pi^2 f_\pi - \sum g_{\sigma i}\rho_i^s = 0$$

For zeta field:

$$k_0\chi^2\zeta - 4k_1(\sigma^2+\zeta^2)\zeta - 4k_2(\zeta^3) - k_3\chi\sigma^2 - \frac{d}{3}\frac{\chi^4}{\zeta} - \left(\frac{\chi}{\chi}\right)^2\left[\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi\right] - \sum g_{\zeta i}\rho_i^s = 0$$

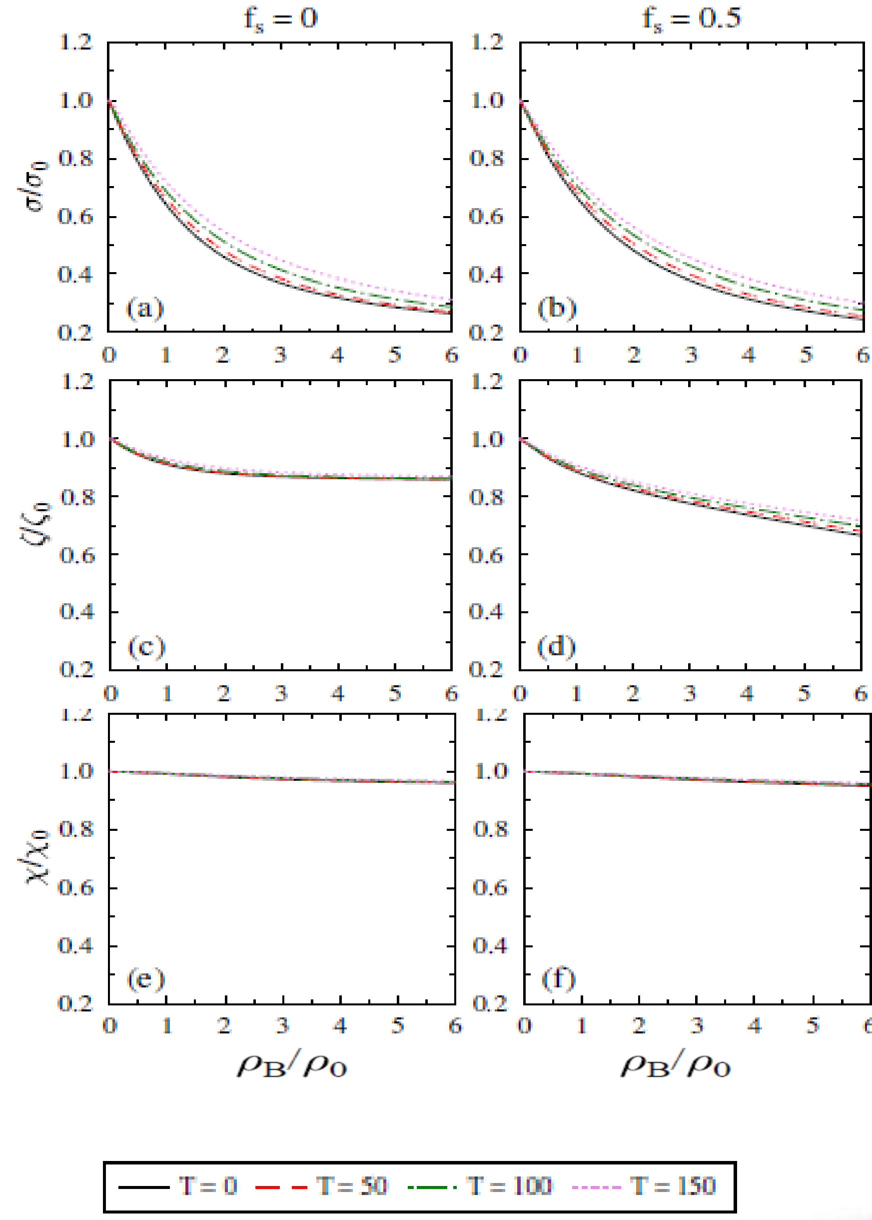
For dilaton field:

$$k_0\chi(\sigma^2+\zeta^2) - k_3\sigma^2\zeta + \chi^3\left[1+\ln\left(\frac{\chi^4}{\chi_0^4}\right)\right] + (4k_4-d)\chi^3 - \frac{4}{3}d\chi^3 ln\left\{\left[\frac{(\sigma^2\zeta)}{\sigma_0^2\zeta_0}\right]\left(\frac{\chi\wedge 4}{\chi_0^4}\right)\right\} + 2\frac{\chi}{\chi_0}\left[m_\pi^2 f_\pi\sigma + \left(\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi\right)\zeta\right] = 0$$

On solving these coupled equations we can calculate the density and temperature dependence of scalar fields σ, ς and dilaton field χ.

Strangeness fraction is defined as $f_s = \frac{\sum_i |s_i| \rho_i}{\rho_B}$.

Where s_i is the number of strange quarks and ρ_i is the number density of ith baryon.

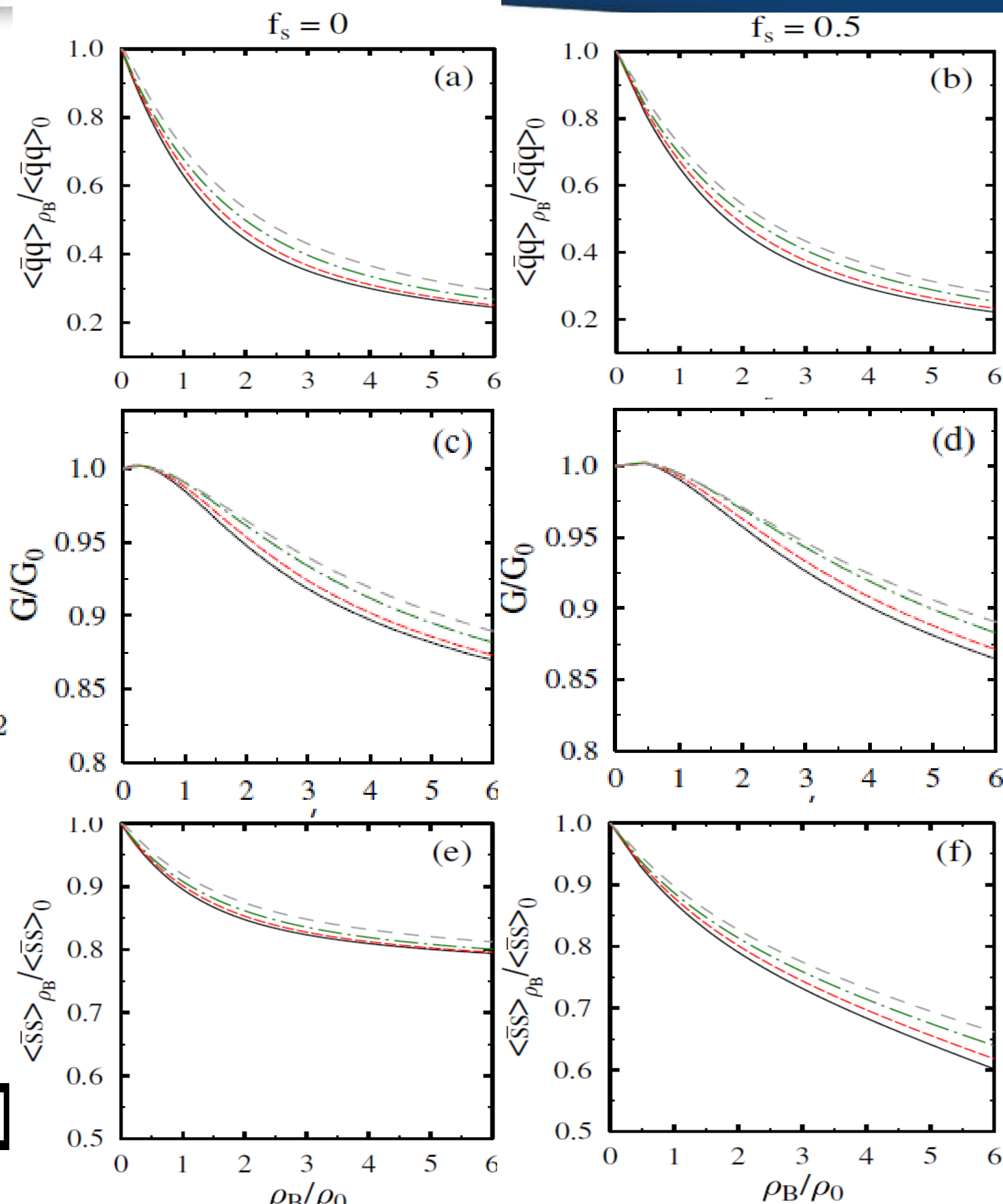


Quark, gluon and strange condensates with temperature and strangeness fraction.

$$\langle \bar{q}q \rangle_{\rho_B} = \frac{1}{2m_q} \left(\frac{\chi}{\chi_0} \right)^2 \left[m_\pi^2 f_\pi \sigma \right].$$

$$\langle \bar{s}s \rangle = \frac{1}{m_s} \left(\frac{\chi}{\chi_0} \right)^2 \left[(\sqrt{2} m_k^2 f_k - \frac{1}{\sqrt{2}} m_\pi^2 f_\pi) \zeta \right]$$

$$\left\langle \frac{\alpha_s}{\pi} G^a{}_{\mu\nu} G^{a\mu\nu} \right\rangle = \frac{8}{9} \left[(1-d)\chi^4 + \left(\frac{\chi}{\chi_0} \right)^2 \left(m_\pi^2 f_\pi \sigma + (\sqrt{2} m_k^2 f_k - \frac{1}{\sqrt{2}} m_\pi^2 f_\pi) \zeta \right) \right]$$



QCD Sum Rule

In QCD Sum rule approach we start with the two point correlation function.

$$\Pi_{\mu\nu}(q) = i\int d^4x\, e^{iq\cdot x}\langle T\{J_\mu(x) J_\nu^\dagger(0)\}\rangle_{\rho_B,T}.$$

Where $J_\mu(x)$ denotes the isospin averaged current $x = x^\mu = (x^0, \mathbf{x})$ Is the four coordinate and $q = q^\mu = (q^0, \mathbf{q})$s the four momentum, and T denotes the time ordered operation on the product of quantities in the brackets.

$$J_\mu(x) = J_\mu^\dagger(x) = \frac{\bar{c}(x)\gamma_\mu q(x) + \bar{q}(x)\gamma_\mu c(x)}{2},$$

Here q denotes light quark and c denotes heavy charm quark.

The two point correlation function:

vacuum part

static one-nucleon part

Pion bath term

$$\Pi_{\mu\nu}(q) \; = \; \Pi^0_{\mu\nu}(q) + \frac{\rho_B}{2M_N} T^N_{\mu\nu}(q) + \Pi^{P.B.}_{\mu\nu}(q) \, ,$$

Where,

$$T^N_{\mu\nu}(\omega, \boldsymbol{q}\,) \; = \; i \int d^4x e^{iq\cdot x} \langle N(p) | T \left\{ J_\mu(x) J^\dagger_\nu(0) \right\} | N(p) \rangle \, .$$

$|N(p)\rangle$ = Spin averaged static nucleon state.

In our present work we take the effect of finite temperature on the σ, vector D and B meson through the temperature dependence of fields ς and χ .

Borel transformation equation can be written as

$$a\left\{\frac{1}{M^2}e^{-\frac{M_{D^*}^2}{M^2}}-\frac{s_0}{M_{D^*}^4}e^{-\frac{s_0}{M^2}}\right\}+b\left\{e^{-\frac{M_{D^*}^2}{M^2}}-\frac{s_0}{M_{D^*}^2}e^{-\frac{s_0}{M^2}}\right\}$$
$$+\ B\left[\frac{1}{(M_H+M_N)^2-M_{D^*}^2}-\frac{1}{M^2}\right]e^{-\frac{M_{D^*}^2}{M^2}}-\frac{B}{(M_H+M_N)^2-M_{D^*}^2}e^{-\frac{(M_H+M_N)^2}{M^2}}$$
$$=\ \left\{-\frac{m_c\langle\bar{q}q\rangle_N}{2}-\frac{2\langle q^\dagger iD_0q\rangle_N}{3}+\frac{m_c^2\langle q^\dagger iD_0q\rangle_N}{M^2}\right\}e^{-\frac{m_c^2}{M^2}}+\frac{m_c\langle\bar{q}g_s\sigma Gq\rangle_N}{3M^2}e^{-\frac{m_c^2}{M^2}}$$
$$+\ \left\{\frac{8m_c\langle\bar{q}iD_0iD_0q\rangle_N}{3M^2}-\frac{m_c^3\langle\bar{q}iD_0iD_0q\rangle_N}{M^4}\right\}e^{-\frac{m_c^2}{M^2}}$$
$$-\frac{1}{24}\langle\frac{\alpha_sGG}{\pi}\rangle_N\int_0^1dx\left(1+\frac{\widetilde{m}_c^2}{2M^2}\right)e^{-\frac{\widetilde{m}_c^2}{M^2}}$$
$$+\ \frac{1}{48M^2}\langle\frac{\alpha_sGG}{\pi}\rangle_N\int_0^1dx\frac{1-x}{x}\left(\widetilde{m}_c^2-\frac{\widetilde{m}_c^4}{M^2}\right)e^{-\frac{\widetilde{m}_c^2}{M^2}}\,.$$

Where $B=\frac{2f_{D^*}^2M_{D^*}^2M_N(M_H+M_N)g_{D^*NH}^2}{(M_H+M_N)^2-M_{D^*}^2}$.

This eqn. has two unknowns a and . b
To solve this we differentiate this eqn w.r.t $\frac{1}{M^2}$
To get two equations with two unknowns.
Solving these two coupled equations we can calculate a and b .

Zhi-Gang Wang, Int. J. Mod Phys. A 28, 1350049 (2013)

Within Chiral SU(3) model we can calculate the values of $\mathcal{O}_{\rho_B}$ at finite density of the nuclear medium, hence can find the $\mathcal{O}_N$

$$\mathcal{O}_N = [\mathcal{O}_{\rho_B} - \mathcal{O}_{vacuum}] \frac{2M_N}{\rho_B}.$$

Here $\mathcal{O}_N$ is nucleon expectation value of the operator at finite baryonic density, $\mathcal{O}_{vacuum}$ is vacuum expectation value of operator, $\mathcal{O}_{\rho_B}$ is the expectation value of operator at finite baryonic density.

In our present investigation of hadrons properties, we are interested in light quark condesates $\bar{u}u$ and $\bar{d}d,$ which are proportional to the non-strange scalar field σ, within chiral SU(3) model. Considering equal mass of light quakrs, u = d = 0.006 GeV. We write,

$$\langle \bar{q}q \rangle_{\rho_B} = \frac{1}{2m_q} \left(\frac{\chi}{\chi_0} \right)^2 \left[m_\pi^2 f_\pi \sigma \right].$$

Quark condensate, $\langle \bar{q}q \rangle_{\rho_B}$ is calculated from the chiral SU(3) model

$\langle \bar{q}q \rangle_{\rho_B}$ Can be used to calculate the other condensates, which are

$$\langle \bar{q} g_s \sigma G q \rangle_{\rho_B} = \lambda^2 \langle \bar{q}q \rangle_{\rho_B} + 3.0 GeV^2 \rho_B.$$

$$\langle \bar{q} i D_0 i D_0 q \rangle_{\rho_B} + \frac{1}{8} \langle \bar{q} g_s \sigma G q \rangle_{\rho_B} = 0.3 GeV^2 \rho_B.$$

Value of the condensate $\langle q^\dagger i D_0 q \rangle$ is not calculated from the chiral SU(3) model. It's value is approximated as $0.18 GeV^2 \rho_B$.

R. Thomas, T. Hilger, B. Kampher, Nucl. Phys. A 795, 19 (2007).

Shift in mass and decay constant

$$\delta M_{D^*} = \sqrt{m_{D^*}^2 + \Delta m_{D^*}^2} - m_{D^*}$$

$$\Delta m_{D^*/D_1}^2 = \frac{\rho_B}{2M_N} \frac{a}{f_{D^*/D_1}^2 M_{D^*/D_1}^2}$$

$$= -\frac{\rho_B}{2M_N} 8\pi (M_N + M_{D^*/D_1}) a_{D^*/D_1} \, ,$$

$$\delta f_{D^*/D_1} = \frac{1}{2 f_{D^*/D_1} m_{D^*/D_1}^2} \left(\frac{\rho_B}{2m_N} b - 2 f_{D^*/D_1}^2 m_{D^*/D_1} \delta m_{D^*/D_1} \right) .$$

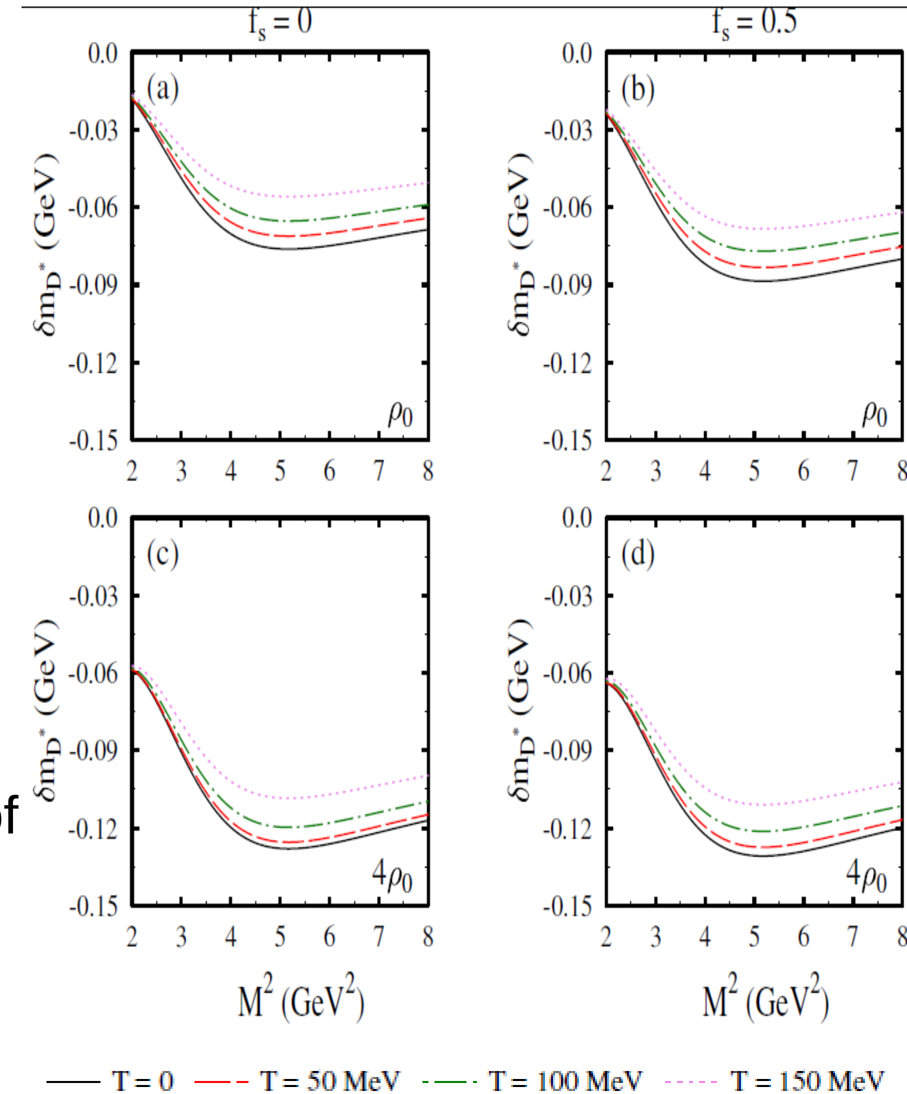
Parameters used

Nuclear saturation density used in the present investigation is 0.15 fm^{-3}. Coupling constant used in this case is $g_{D^* N \Lambda_c} \approx g_{D^* N \Sigma_c} \approx g_{B^* N \Lambda_b} \approx g_{B^* N \Sigma_b} \approx$ 3.86. The masses of mesons m_{D^*}, m_{B^*}, $m_{D_s^*}$ and $m_{B_s^*}$ are 2.01, 5.325,2.112 and 5.415 MeV respectively. Values of decay constants of f_{D^*}, f_{B^*}, $f_{D_s^*}$ and $f_{B_s^*}$ are 0.270, 0.195,1.16*f_{D^*} and 1.16*f_{B^*} respectively. Masses of quarks namely (up)u , (down)d, strange(s), (charm)c and (bottom)b are taken as 0.006, 0.006, 0.095, 1.35 and 4.7 GeV respectively. Values of threshold parameter s_0 used in the present investigations for D^*, B^*, D_S^* and B_S^* mesons are 6.5, 35, 7.5 and 38 GeV^2 respectively. To represent the exact mass and decay shift we chose a suitable Borel window within which there is almost no variation in the mass and decay constant.

Arvind kumar and Rahul chhabra
arxiv:1506.02115

Qualitative Results and Discussion

D^* Meson Mass Shift :



Temperature : decreases the magnitude of shift in mass

Strange medium f_s : Increases the magnitude of mass shift.

Density ρ_B : Increases the magnitude of mass shift.

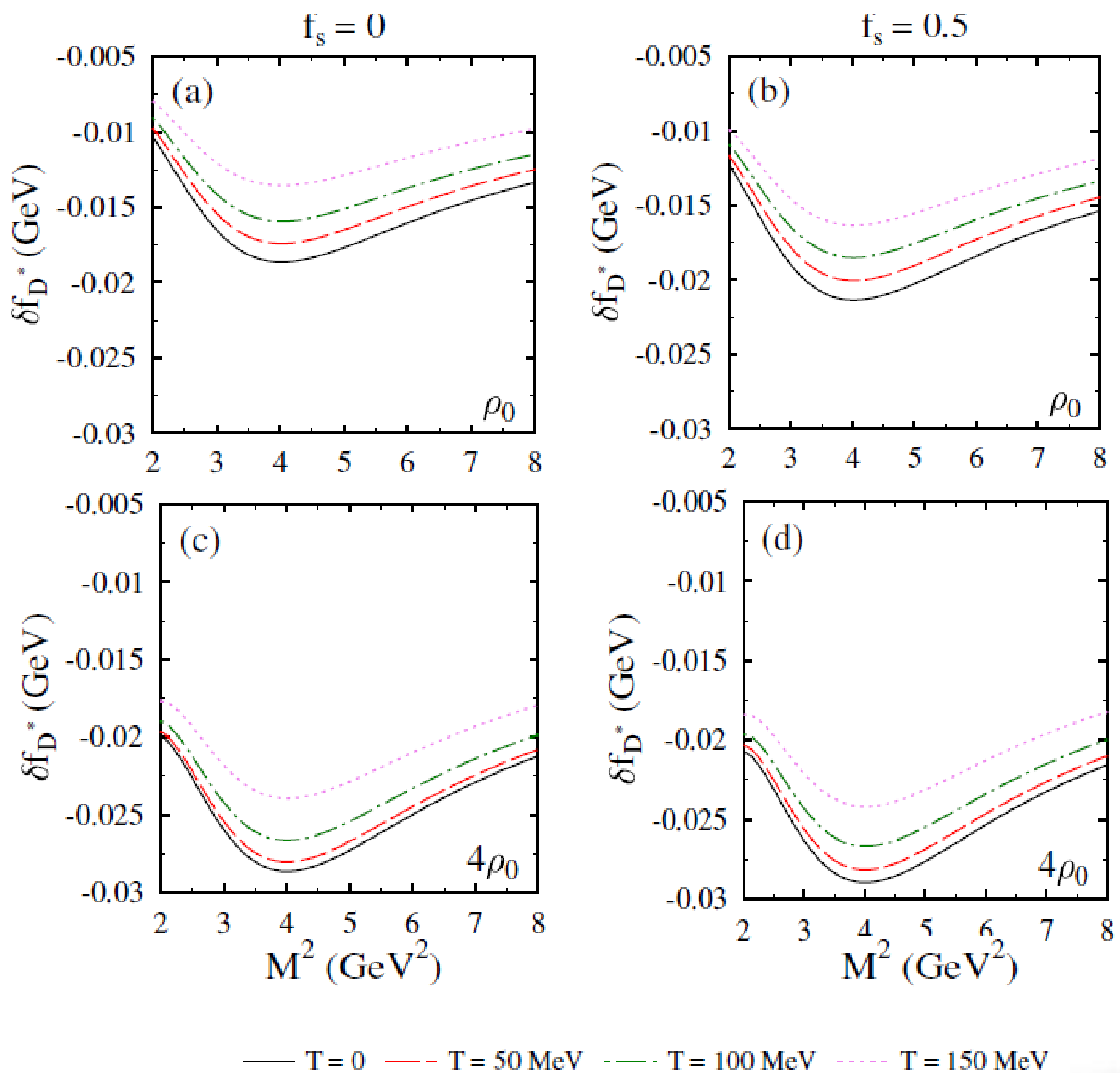
D^* Decay Shift:

❖ Negative decay shift of vector D meson

❖ With increase in the density of the medium (from fig.(a) to (c) or fig.(b) to (d))magnitude of the shift in decay constant increase.

❖ On increase in temperature the magnitude of decay shift decrease.

❖ On moving from non-strange to strange medium decay constant decrease more from its vacuum value.



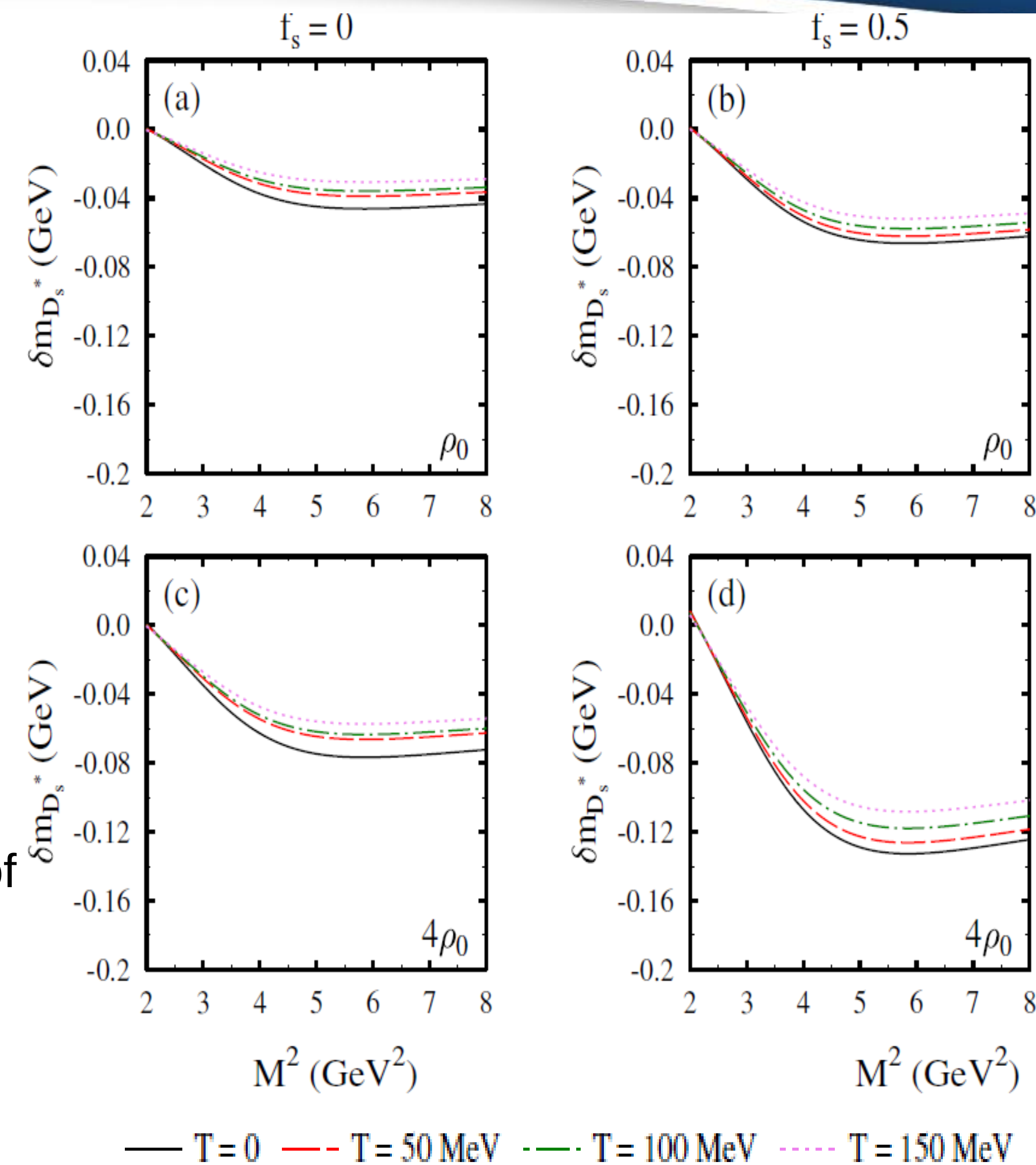
D_s^*

Effect on Mass shift:

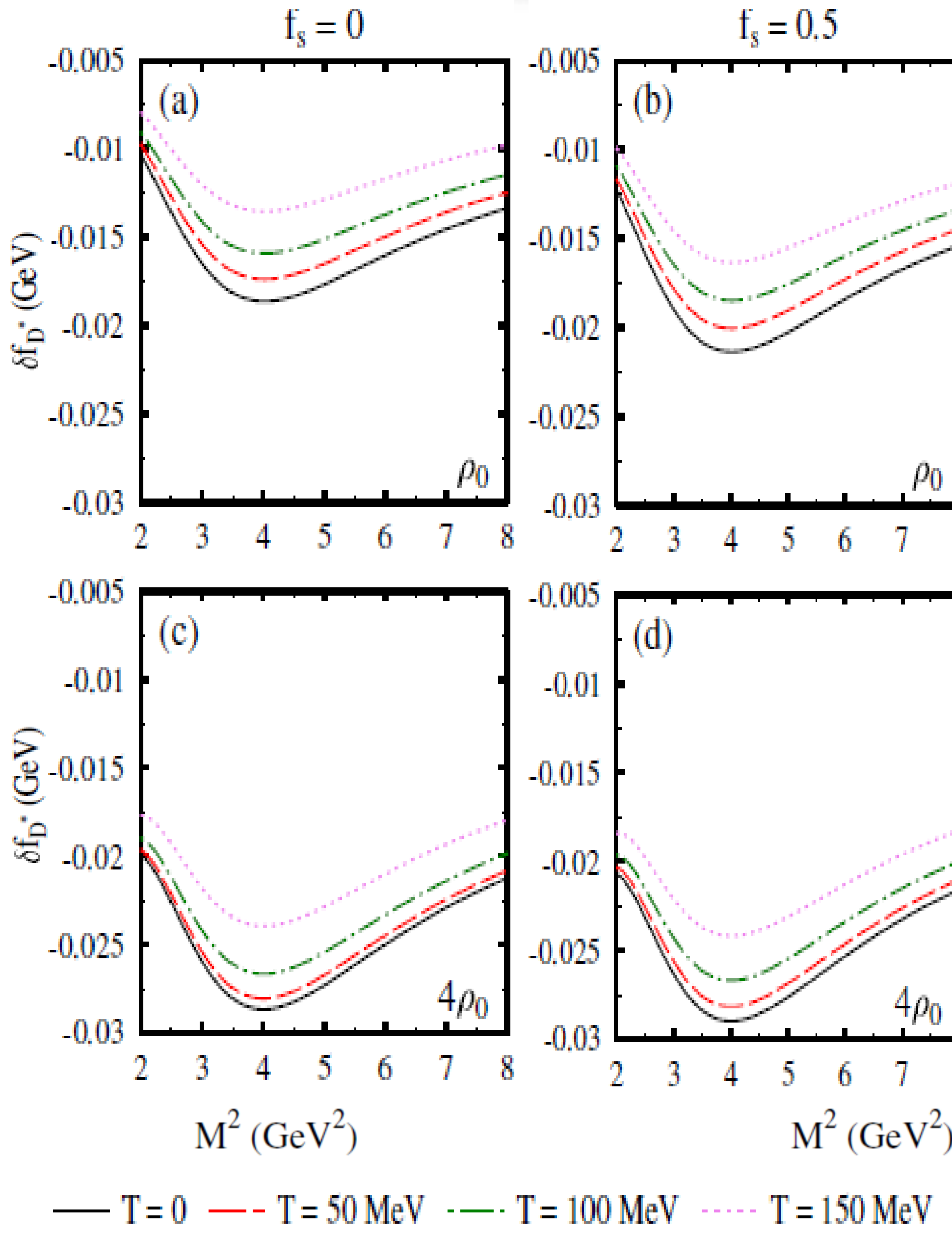
Temperature : Decreases the magnitude of shift in mass

Strange Medium : Increases the magnitude of mass shift

Density : Increases the magnitude of mass shift.



D_s^*



Effect on Decay Constant

Temperature : Decreases the magnitude of decay shift.

Strangeness fraction : Increases the magnitude of mass shift.

Density : Increases the magnitude of mass shift.

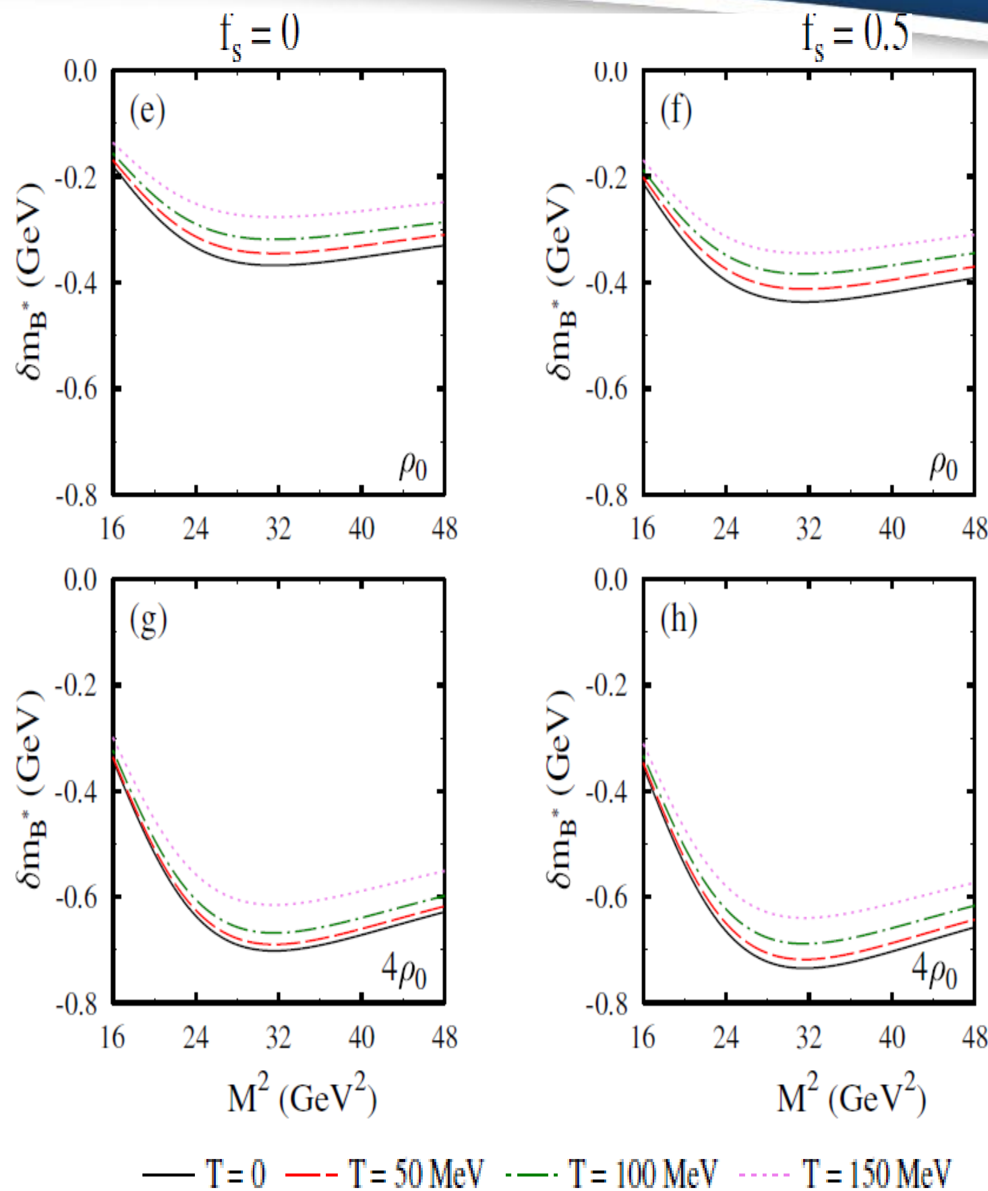
B^*

Effect on Mass

Temperature : decreases the magnitude of shift in mass

Strange Medium : Increases the magnitude of mass shift

Density : Increases the magnitude of mass shift.



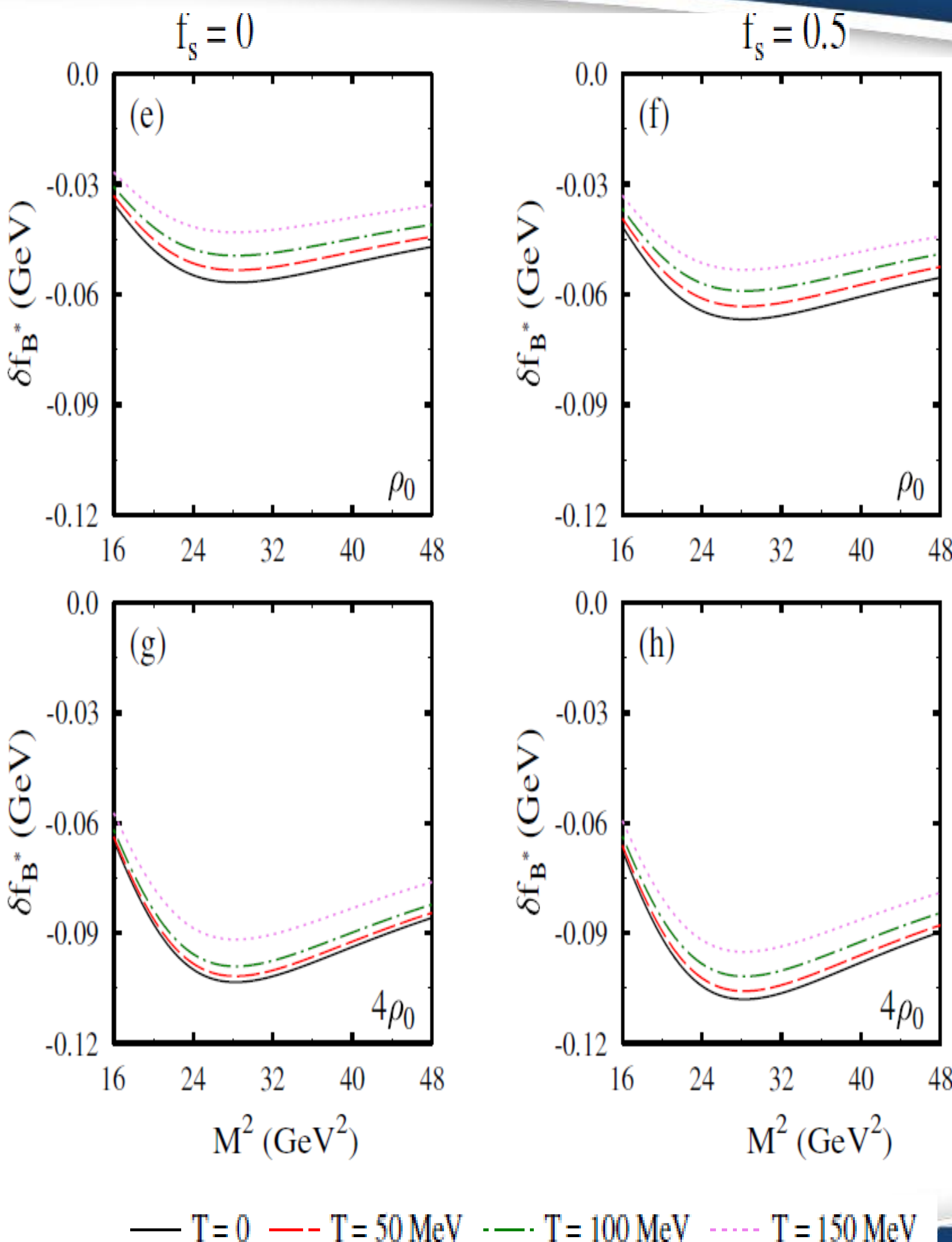
B^*

Effect on Decay Constant

Temperature : decreases the magnitude of shift in decay constant

Strange Medium : Increases the magnitude of mass shift

Density : Increases the magnitude of mass shift.



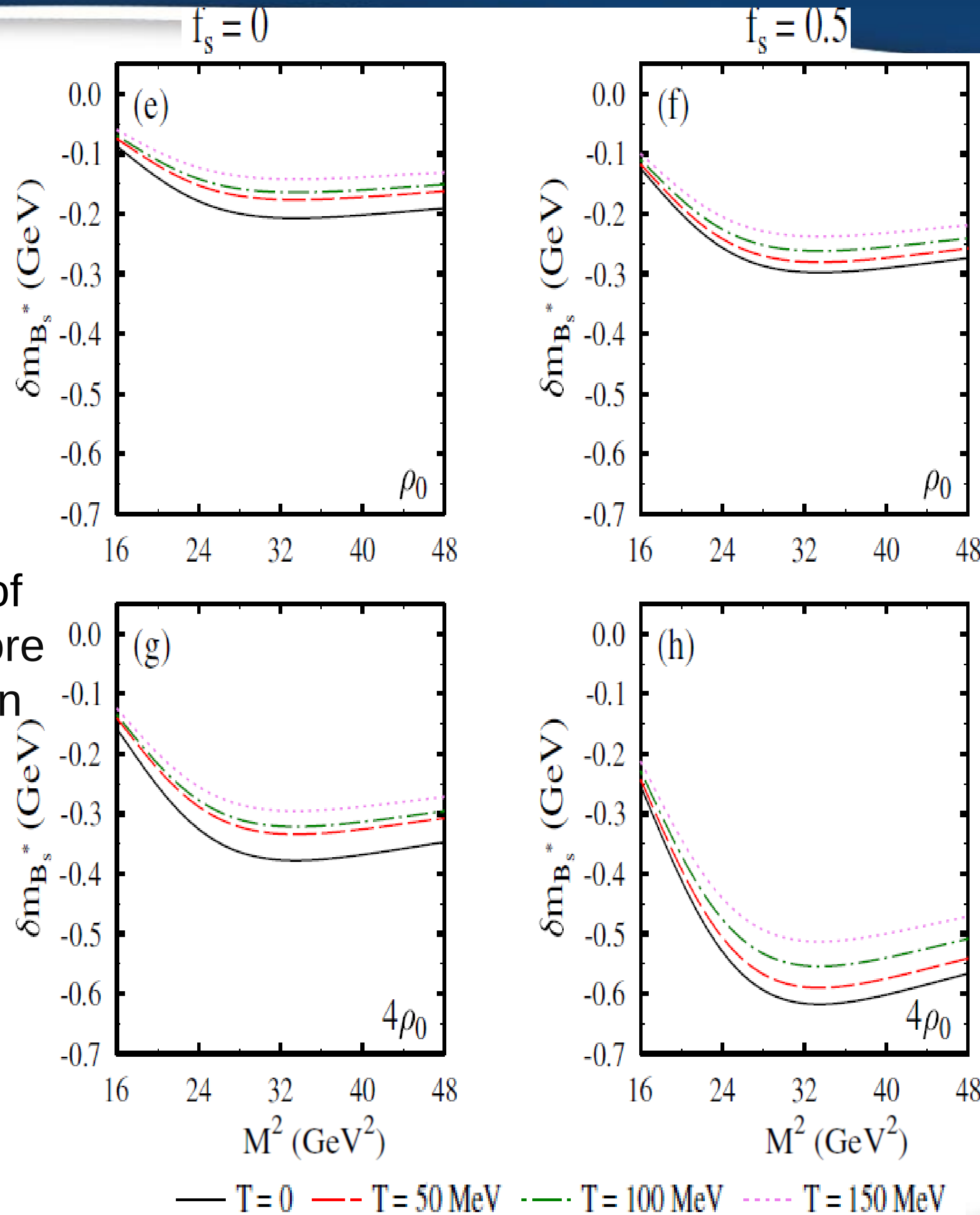
B_s^*

Effect on Mass

Temperature : decreases the magnitude of shift in mass

Strange Medium : In strange medium value of shift in mass decrease more from its vacuum value than in the nuclear medium. of mass shift

Density : Increases the magnitude of mass shift.



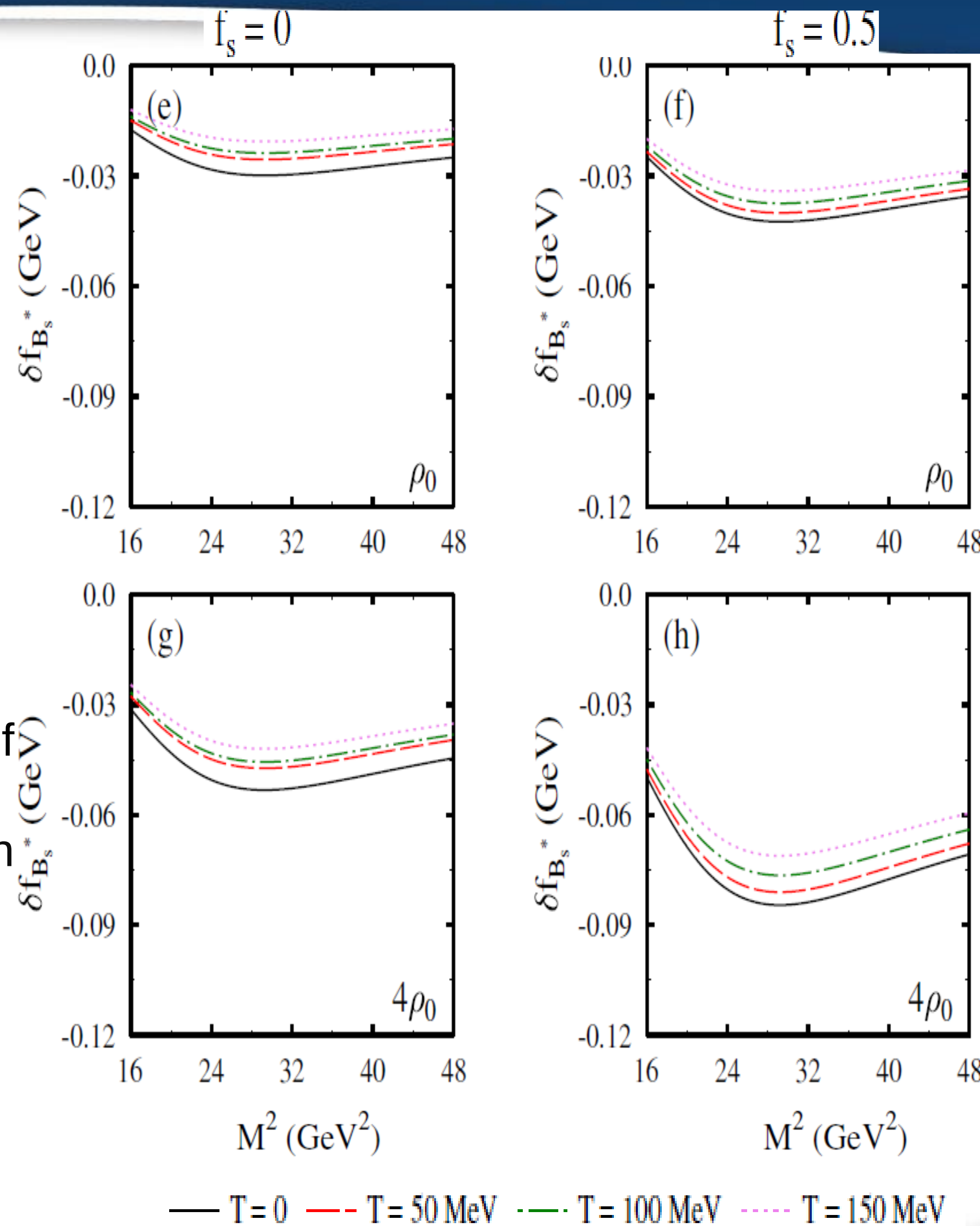
B_s^*

Effect on Decay Constant

Temperature : decreases the magnitude of shift in decay constant

Strange Medium : In strange medium value of decay shift decrease more from its vacuum value than in the nuclear medium.

Density : Increases the magnitude of decay shift.



COMPARISON

- Coupled channel approach Phys. Rev. C 80, 065202 (2009) Mass shift of Vector D meson is positive. Which indicates repulsive interactions in the medium.

- Using QCD sum rule Int. J. Mod. Phys.A 28(2013)1350049 observed the mass sift of vector D and B mesons as -71 and 380 MeV.

- Using QCD sum rule arxiv :1501.05093[hep-ph] studied the shift in the mass(decay constant) of vector D and B mesons as -70(-16) and -340(-55) MeV respectively.

- In the present investigation using Chiral SU(3) model and QCD sum rule shift in mass(decay constant) of vector D and B mesons as -76(-18) and -437(-56) MeV in non-strange medium at zero temperature.

Summary

- We have used chiral model and QCD sum rule approach to observe the effect of strange medium, temperature and baryonic density on the shift in masses and decay constants of vector D and B mesons.

- Strange medium decrease the value of mass and decay constants of D^*, B^*, D_s^*, B_s^*.

- With increase in the temperature of the medium magnitude of shift decrease.

- With increase in density of the medium magnitude of shift increase.