Baryon Number Fluctuations

-- medium modifications and parity doubling --

Ref. Koch, Marczenko, Redlich, CS, arXiv:2308.15794

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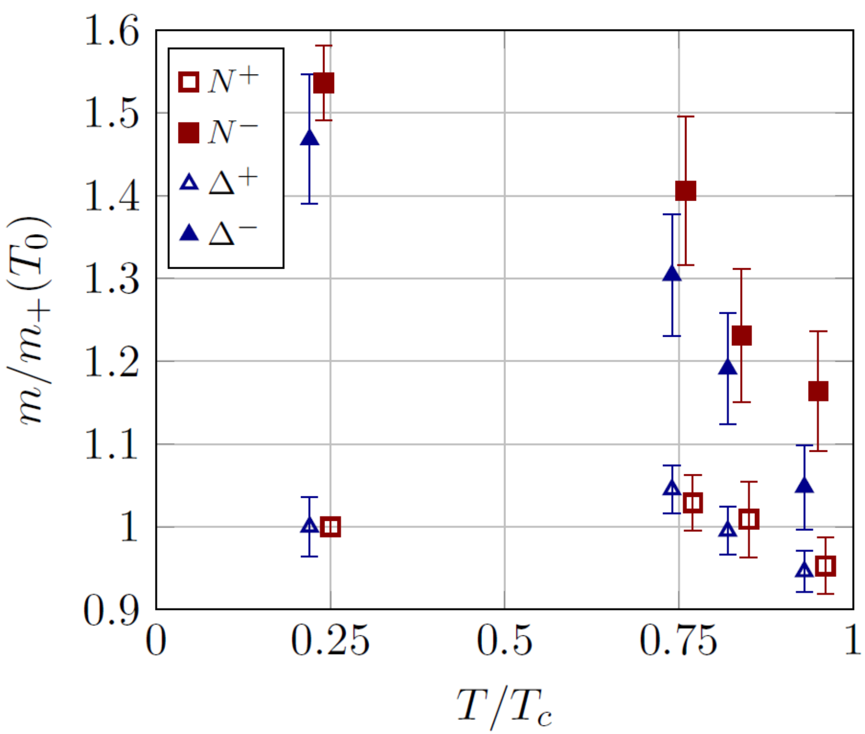
Fate of hadrons in matter

Unbroken chiral symmetry → **parity doubling**

- In reality, the mass different is huge.
- Degenerate parity partners at high T/ρ_B as signatures of chiral symmetry restoration!



LQCD at finite T & zero μ

- Spatial masses, DeTar-Kogut, 1987
- Temporal masses, FASTSUM Collab., 2017-19

Net proton vs. baryon number fluct.

χ_2^B sensitive to the QCD phase transition

→Net proton fluctuations as a good proxy for net baryon fluctuations: folklore

✓Nucleon parity doublet: N(939) & N*(1535)

- Mean: $\langle N_B \rangle \equiv \kappa_1^B = \kappa_1^+ + \kappa_1^-$
- Variance: $\langle \delta N_B \delta N_B \rangle \equiv \kappa_2^B = \kappa_2^{++} + \kappa_2^{--} + 2\kappa_2^{+-}$
- Cumulants → susceptibilities:

$$\kappa_n^B = VT^3 \chi_n^B \qquad \chi_2^B = \chi_2^{++} + \chi_2^{--} + 2\chi_2^{+-}$$

- Sign and strength of χ_2^{+-}?

DeTar-Kunihiro/Parity doublet model

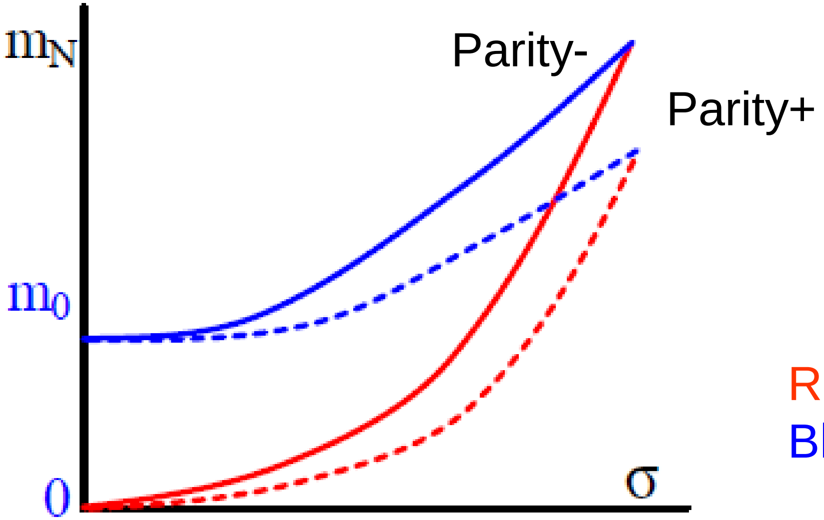
- SU(2) chiral transformation of 2 nucleons

  → how to assign 2 indep. rotation to them?

$$\psi_{1L} \to g_l\, \psi_{1L}\,, \quad \psi_{1R} \to g_r\, \psi_{1R} \;\sim\; \psi_{1L} : (1/2, 0) \quad \psi_{1R} : (0, 1/2)$$

$$\psi_{2L} \to g_r\, \psi_{2L}\,, \quad \psi_{2R} \to g_l\, \psi_{2R} \;\sim\; \psi_{2L} : (0, 1/2) \quad \psi_{2R} : (1/2, 0)$$

$$\mathcal{L}_m = m_0 \left(\bar{\psi}_2 \gamma_5 \psi_1 - \bar{\psi}_1 \gamma_5 \psi_2 \right) \;\Rightarrow\; m_{N_\pm} = \frac{1}{2}\left[\sqrt{c_1 \sigma^2 + 4 m_0^2} \mp c_2 \sigma \right]$$

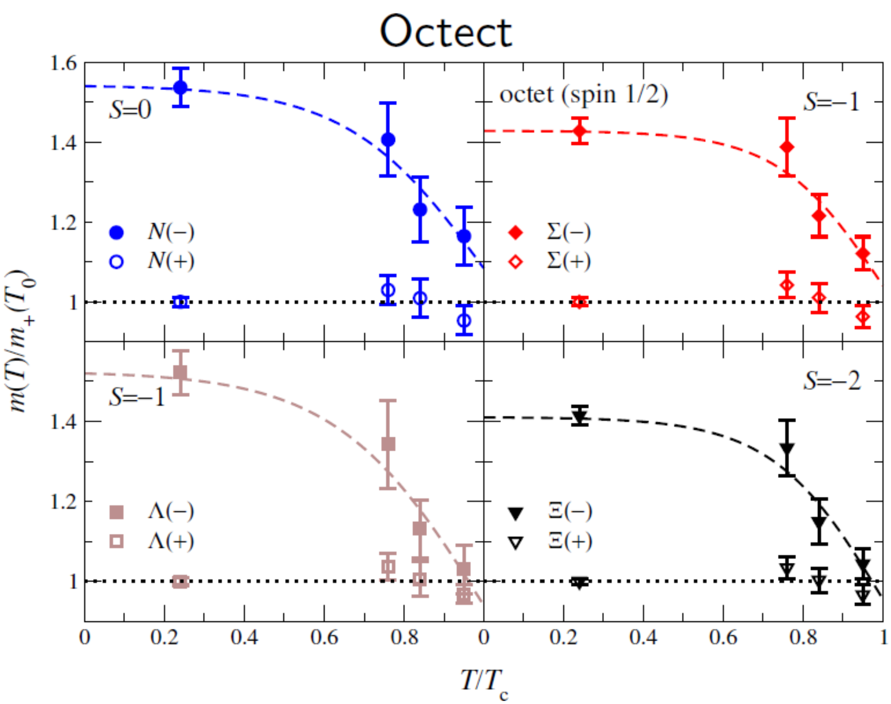


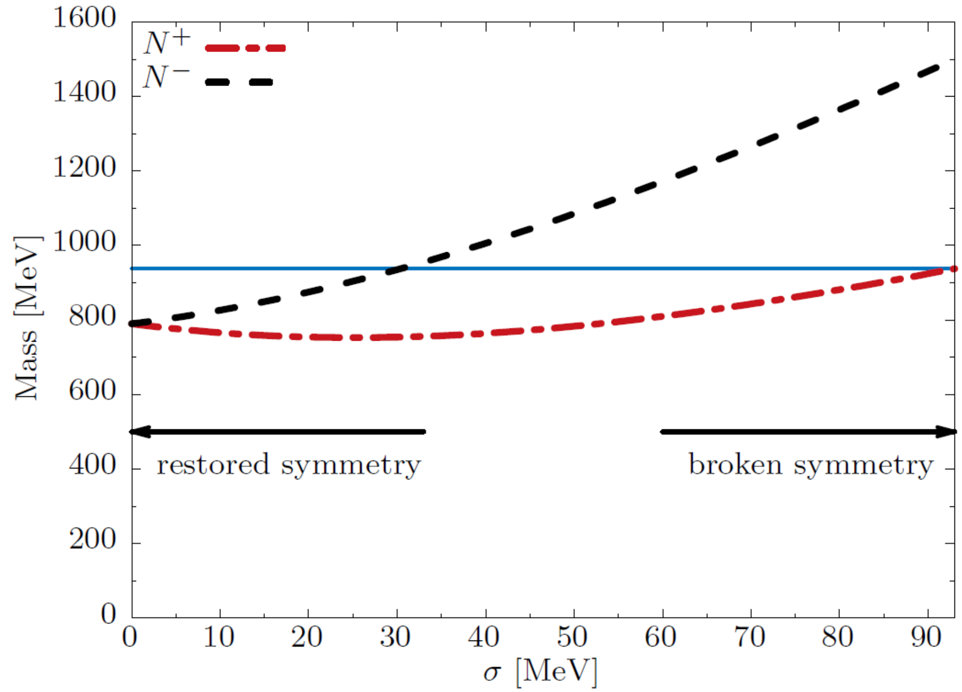
[DeTar-Kunihiro, 1989]

Red: standard

Blue: Mirror

Parity doubling of baryons





- Lattice QCD at zero μ [Aarts et al., 2016]
- Survival mass $m_N \approx m_0 \neq 0$ [DeTar, Kunihiro, 1989]

$$M_{\pm} = \sqrt{m_0^2 + c_1^2\sigma^2} \mp c_2\sigma \xrightarrow{\sigma \to 0} m_0$$

Thermodynamics of parity doubler

Linear sigma model for (σ,π), ω, (N,N*) & MF

- New chemical potentials $\mu_{+,-}$ for N,N*
- Set at the end $\mu_{\pm} = \mu_N = \mu_B - g_\omega \omega$
- Susceptibilities from thermodynamics pot.

$$\Omega = \Omega_+ + \Omega_- + V_\sigma + V_\omega$$

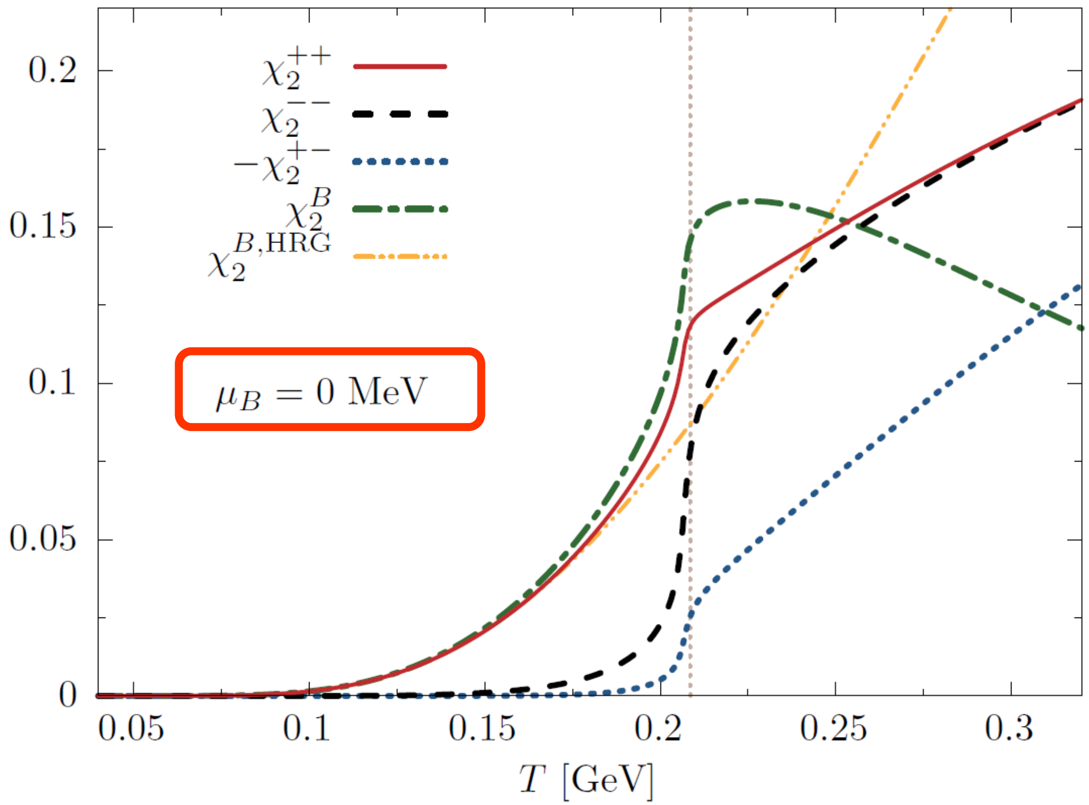
$$0 = \frac{\partial \Omega}{\partial \sigma}$$

$$0 = \frac{\partial \Omega}{\partial \omega}$$

$$\chi_2^{\alpha\beta} = \frac{1}{VT^3}\kappa_2^{\alpha\beta} = -\left.\frac{\mathrm{d}^2\hat{\Omega}}{\mathrm{d}\hat{\mu}_\alpha \mathrm{d}\hat{\mu}_\beta}\right|_{T,\mu_\alpha=\mu_\beta=\mu_N}$$

$$\chi_2^B = \chi_2^{++} + \chi_2^{--} + 2\chi_2^{+-}$$

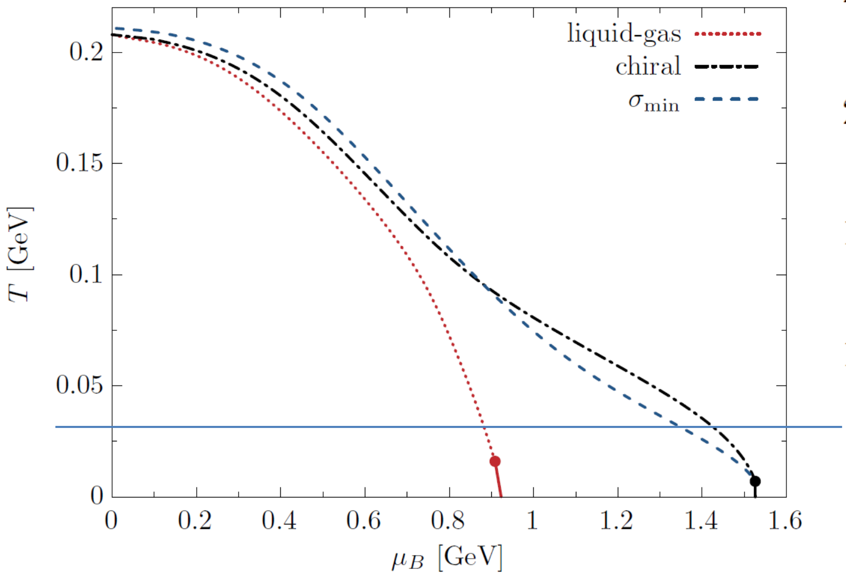
Correlations between N & N*

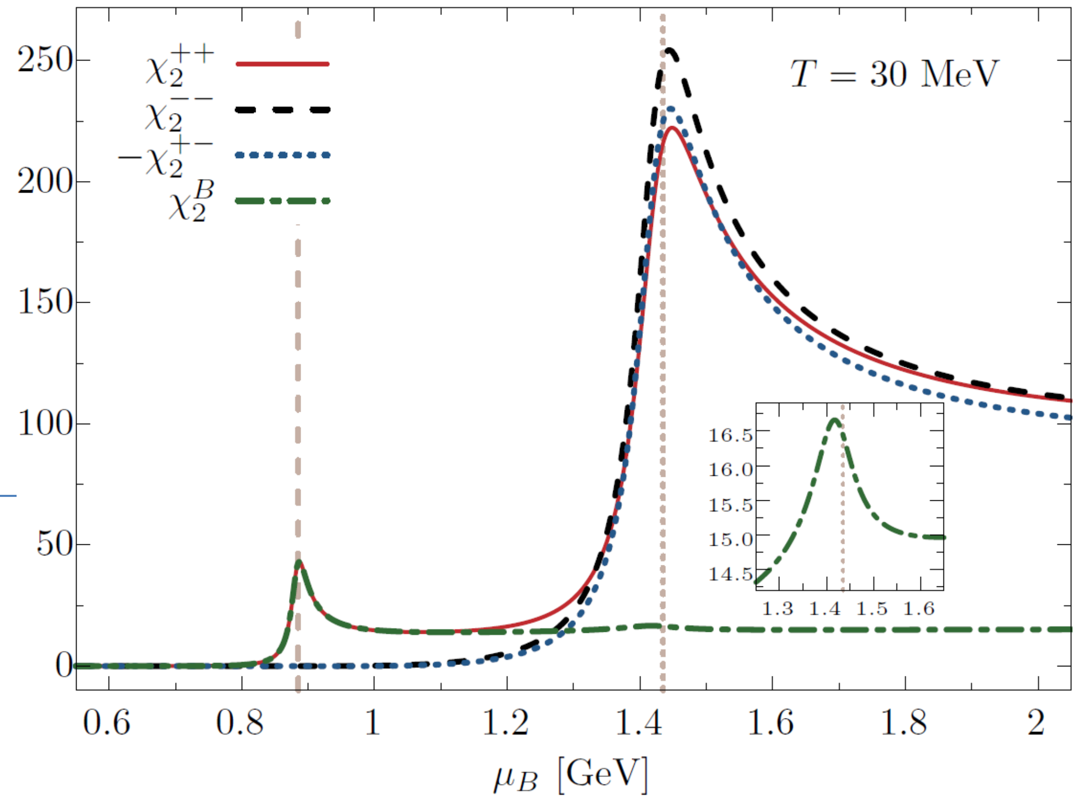


- ❑ χ_2^B dominated by positive-parity fluct.
- ❑ N* being relevant only near Tc
- ❑ χ_2^{+-} sets in only near Tc, and it's **negative**.
- ❑ χ_2^{+-} becomes more negative with repulsive int.

Linear sigma model & nucleon parity doubler

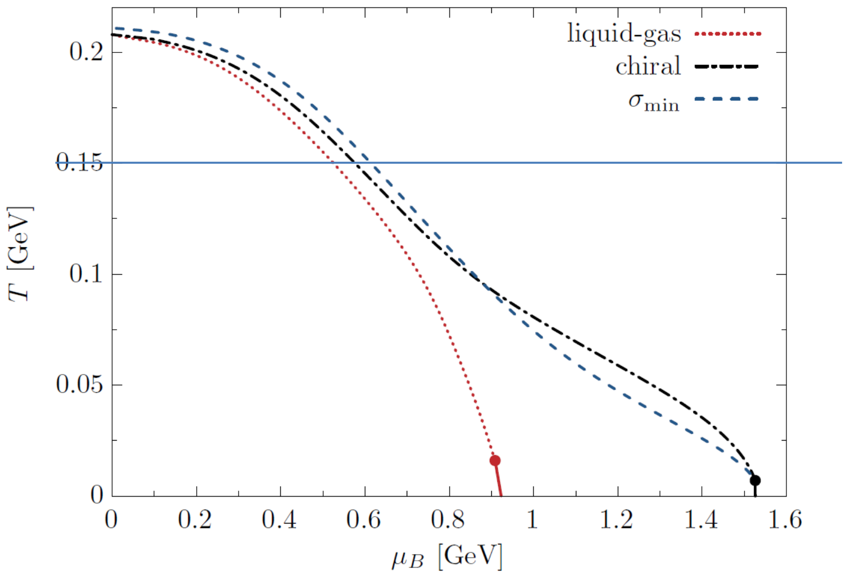
Liquid-gas vs. chiral

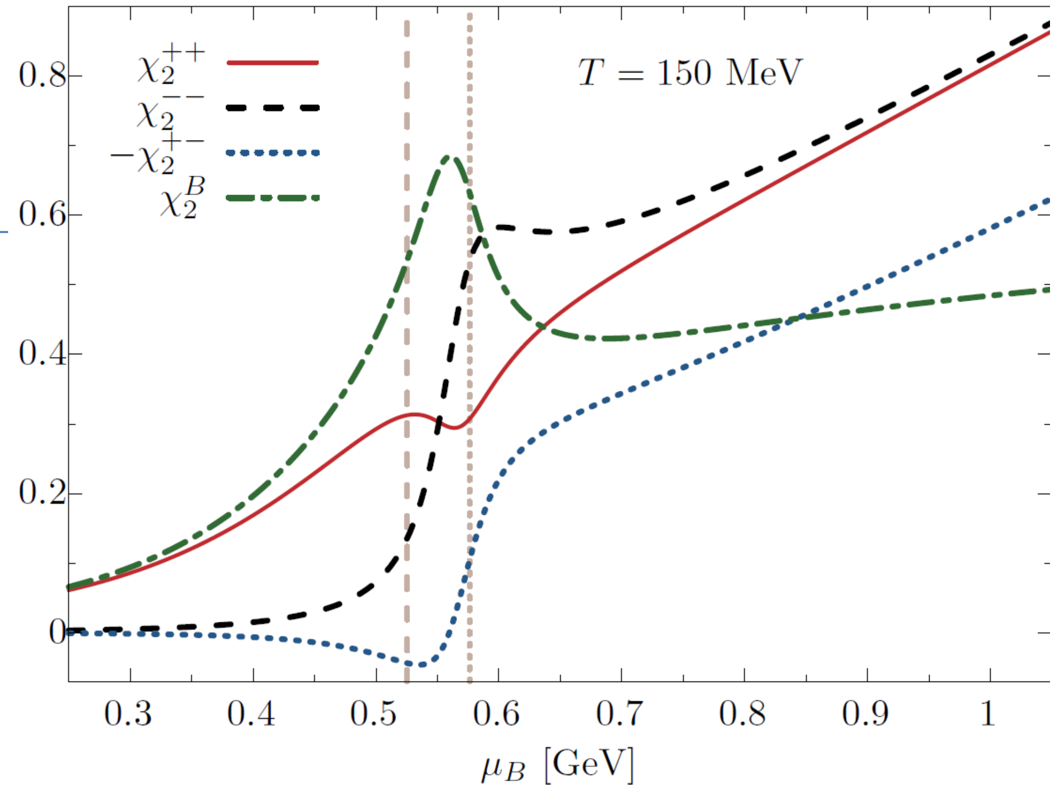




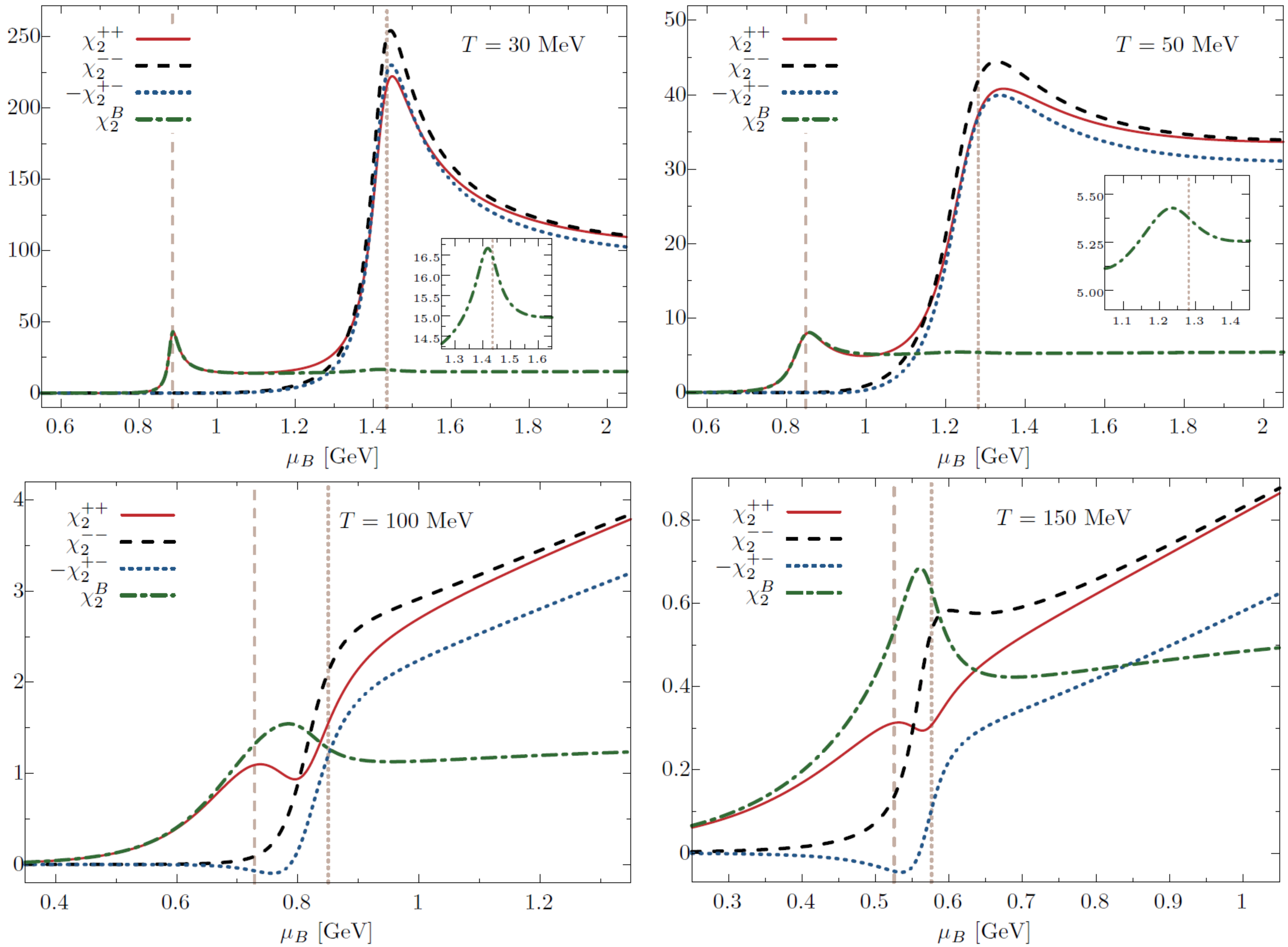
- ❑ LG dominated by χ_2^{++}
- ❑ Chiral dominated by both, but $\chi_2^{--} > \chi_2^{++}$
- ❑ Peaks diminished by χ_2^{+-} ➔ weak signal in χ_2^{B}

Liquid-gas vs. chiral





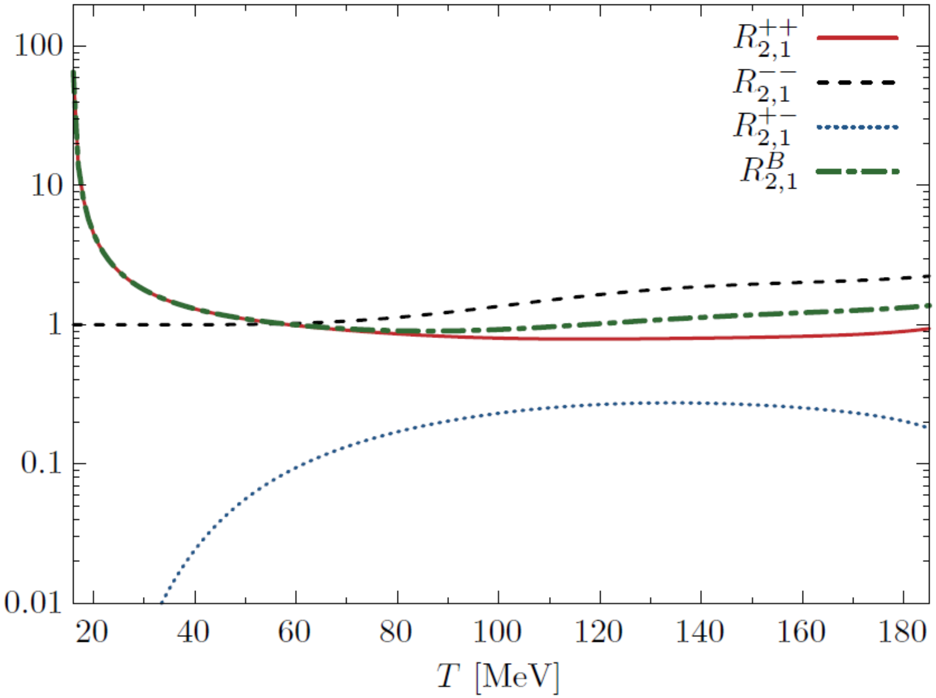
- Increasing T ➔ 2 peaks getting closer
- Qualitative difference of χ_2^{++} from χ_2^{--}
- Stronger signal left in χ_2^{B}



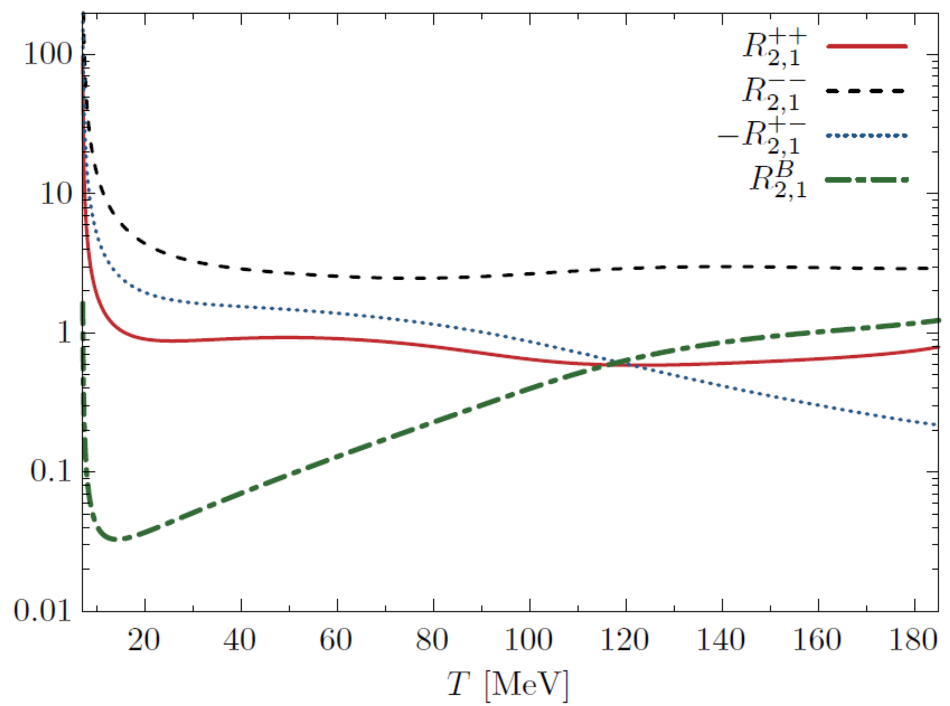
$T = 30$ MeV
$T = 50$ MeV
$T = 100$ MeV
$T = 150$ MeV
χ_2^{++}
χ_2^{--}
$-\chi_2^{+-}$
χ_2^{B}
μ_B [GeV]

χ_2/χ_1 along the phase boundary

↓ CP of LG



↓ QCD CP



- The net-proton fluctuations do not necessarily reflect the net-baryon fluctuations at the chiral phase boundary.

SUMMARY

Concluding remarks

- Negative correlation between N and N*
- $\chi_2^{++\approx \mathrm{proton}}$ may not reflect χ_2^B at the chiral phase boundary.
- Proposition: $\chi_2^{++,--,+-}$ in other non-perturbative approaches.