Pseudoscalar Screening Mass at Finite Temperature and Magnetic Field

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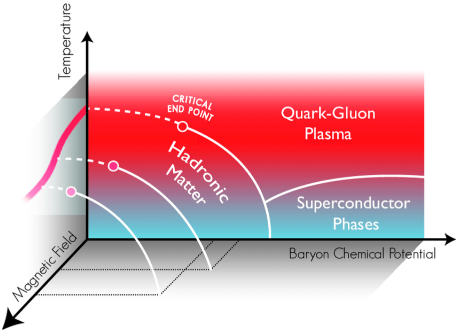
Motivation



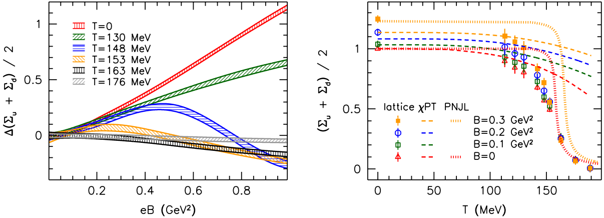
[Source: P. Costa, et al., arXiv:1712.08387v1]

Strong interacting medium
+
magnetic field

- Early universe
- Neutron stars
- Heavy ion collisions

Effects of magnetic field on strong interacting matter

Magnetic catalysis (MC)	Inverse Magnetic catalysis (IMC)
Observed at zero temperature	Observed near T_{pc}
Chiral condensate enhanced	Chiral condensate suppressed
led to theoretical prediction of increased T_{pc}	lattice results show decreased T_{pc}
Valence quarks dominate	Sea quarks dominate
[Buividovich et al., PhysLetB.2009.11.017, D'Elia et al., PhysRevD 82.051501, H.-T. Ding et al., PhysRevD.104.014505]	[Bali et al., Phys.Rev.D.86.071502, Bruckman et al., JHEP04(2013)112, H.-T. Ding et al., Phys.Rev.D105,034514]



[Bali et al., hys. Rev. D 86, 071502]

Rleated reviews:
Endrodi arXiv:2406.19780
Andersen et al., Rev.Mod.Phys. 88, 025001
Kharzeev et al. Springer Vol. 871, 201

Ward Identity: relates chiral condensate with chiral susceptibility [H.-T. Ding et al. PhysRevD.104.014505]

$$(m_u + m_d)\,\chi_{\pi^0} = \langle\bar{\psi}\psi\rangle_u + \langle\bar{\psi}\psi\rangle_d$$

Chiral susceptibility χ_H: integrated screening correlator

$$\chi_H = \int dz \; C_H(z)$$

Screening correlators $C_H(z)$: two point correlation function of pseudoscalar meson H propagating in spatial direction z

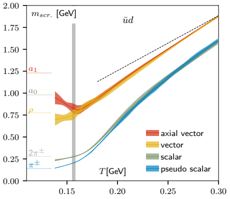
$$C_H(z,T) = \int_0^{1/T} d\tau \int dx \int dy \langle J_H^\dagger(x,y,z,\tau) J_H(0,0,0,0)\rangle$$

At large distances, the screening correlator decays exponentially giving us the screening mass M

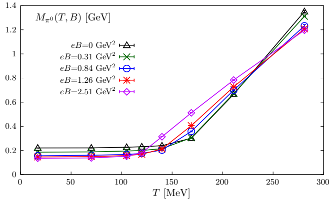
$$z \to \infty, \qquad C(z) \to e^{-zM(T)}$$

The inverse of a screening mass M is the screening length, i.e., the spatial distance beyond which the effects of a test hadron are effectively screened.

- How does the long distance behavior of correlation function depend on the magnetic field?
- Does it have a similar behavior like chiral condensate?



[HotQCD, PhysRevD.100.094510]



H.-T. Ding et al., Phys.Rev.D105,034514

- A long history of screening mass analysis at zero magnetic field
  DeTar, Kogut, Phys.Rev.Lett.59.399, Gottlieb et al.,Phys.Rev.Lett.59.1881, Forcrand et al.,Phys.Rev.D63.054501, Gavai et al., Phys.Rev.D67.034501, [HotQCD,EPJC,71(2):113,2011, PhysRevD.100.094510]
- Screening mass at finite magnetic field: H.-T. Ding et al., Phys.Rev.D105,034514 described the behavior of lattice screening mass on a wide temperature range at $M_\pi = 220$ MeV
- Our goal:
  1. zoom in near critical point to observe dominant effect
  2. continuum extrapolated pseudoscalar screening mass near T_{pc} at physical quark mass.

Lattice setup

- A tree-level improved Symanzik gauge action lattices with $N_f = 2+1$ with Highly improved staggered quarks (HISQ) and uniform magnetic fields along the z direction used.
- $N_\tau = 8, 12, 16$ with aspect ratio $N_\sigma / N\tau = 4$ fixed.
- Scale set by fixing the kaon decay constant $f_K = 156.1/\sqrt{2}$ MeV.
  HotQCD, Phys.Rev.D90,094503, PhysRevD.100.094510
- The strange quark mass m_s tuned to its physical value by fixing $M_{\eta_{s\bar{s}}} = 686$ MeV and light quark mass $m_l = m_s/27$.
- The magnetic flux on the lattice is quantized using the formulation

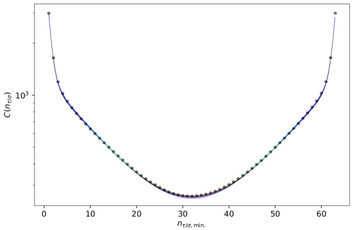
$$eB = \frac{6\pi N_b}{N_\sigma^2 a^2} = 6\pi N_b T^2 \frac{N_\tau^2}{N_\sigma^2} \tag{1}$$

- Temperatures range: T = 145 to 166 MeV
- Magnetic flux: Nb = 1, 2, 3, 4, 6, 12, 16, 24
- Magnetic field strengths range: eB = 0 to 0.8 GeV^2

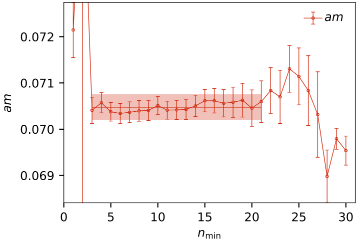
Screening mass on lattice

The periodic boundary on lattice results in a symmetric behavior of the correlator given by

$$C(n_z) = \Sigma_i A_i \cosh\left(M_i(n_z - N_\sigma/2)\right) \quad (2)$$



Screening correlator for $\pi^0 = \frac{1}{2}(dd + uu)$ channel, lattice dim $= 64^3 \times 16$, with magnetic field eB $= 0.22\text{GeV}^2$.



Plateau fitting for screening mass for $\pi^0 = \frac{1}{2}(dd + uu)$ channel, lattice dim $= 64^3 \times 16$, with magnetic field eB $= 0.22\text{GeV}^2$.

Continuum extrapolation

- Use the lattice observable O for each N_τ and perform a 2D interpolation in T-B plane.
- Given our action has a correction of $\boldsymbol{O}(a^2)$, we perform the continuum extrapolation in N_τ^2 using a linear ansatz on two finest lattices and quadratic ansatz on all three lattices

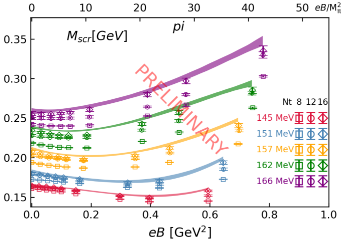
$$O_{N_\tau} = O_{cont}^{linear} + \frac{b}{N_\tau^2} \tag{3}$$

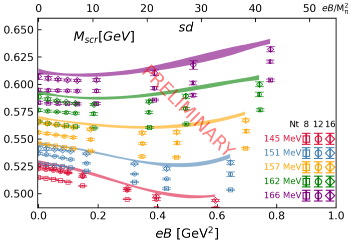
$$O_{N_\tau} = O_{cont}^{quadratic} + \frac{b}{N_\tau^2} + \frac{c}{N_\tau^4} \tag{4}$$

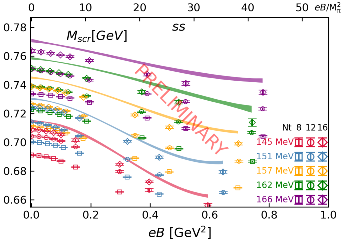
- Considering the values obtained from linear and quadratic methods as independent values, we obtain the continuum screening mass

$$O_{cont} = \frac{1}{2}(O_{cont}^{linear} + O_{cont}^{quadratic}) \tag{5}$$

Neutral meson: Screening Mass vs Magnetic Field

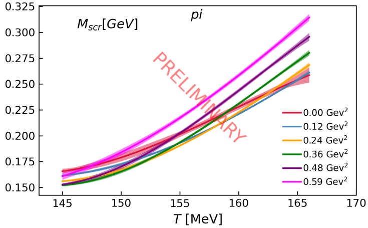


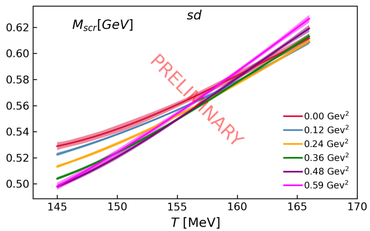


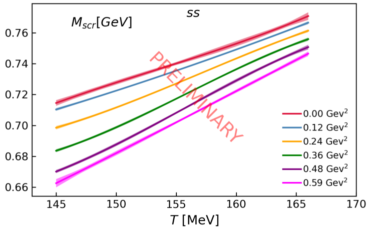


- H. Ding et al., 2022 showed dominatingly decrease screening mass at very high and very low temperatures.
- Near T_{pc}, a minima beyond which the screening mass increases
- The magnetic field at which minima occurs decreases with increased temperature
- The minima shifts at larger magnetic field for mesons with larger mass

Neutral meson: Screening Mass vs Temperature

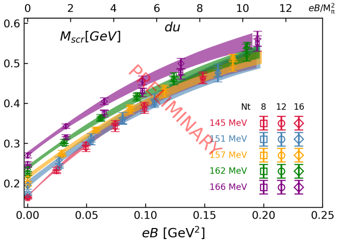






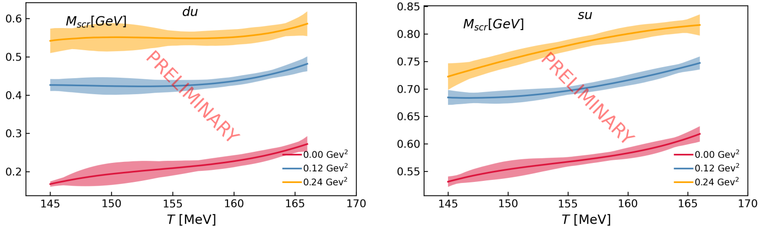
- Near T_{pc}, screening mass at fixed magnetic field cross each other
- Crossing temperature increase with increasing meson mass
- Screening mass crossing not observed in our range temperature for ss meson

Charged meson: Screening Mass vs Magnetic Field



- The charged meson screening mass steadily increase with increasing magnetic field strength
- The increase seem to approach a constant with increasing magnetic field strength

Charged meson: Screening Mass vs Temperature



- The charged meson screening mass at constant magnetic field strength increase with temperature

Summary

- Numerical estimates of continuum extrapolated neutral and charged meson screening mass
- Continnuum extrapolated neutral pseudoscalar screening mass near the T_{pc} indicate large distance behavior have similar behavior like chiral condensate, i.e.,
    1. early deviation from a T=0 mass at larger magnetic field
    2. suppression of the magnetic effect with increased meson mass
- Charged pseudoscalar screening mass increase with increasing magnetic field.