Polarization Dynamics in Charged Magnetized Quark-Gluon Plasma Polarization Dynamics in Charged Magnetized

(Center Gluon Plasma

(Center for Fundamental Physics, AUST)

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Quark-Gluon Plasma

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Quark-Gluon Plasma

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Center for Fundamental Physics,

热烈祝贺安徽理工大学基础物理研究中心成立!

Cundamental Physics, AUST Center for Fundamental Physics, AUST Center for

Shu Lin Sun Yat-Sen University

Outline

Center for Fundamental Physics,

- Magnetic field induced phases and transports
- Uncertainty in magnetic field in heavy ion collisions $\begin{array}{cc} C_{\odot_{\gamma_{\tilde{f}_{\odot}}}} & & \frac{1}{\gamma_{\tilde{f}_{\beta_{\gamma_{\tilde{f}_{\beta_{\gamma_{\tilde{f}_{\beta_{\gamma_{\tilde{f}_{\beta_{\tilde{f}}}}}}}}}}}}\ \text{and} \end{array}$
 $\begin{array}{cc} \text{transports} & & \frac{1}{\gamma_{\tilde{f}_{\gamma_{\tilde{f}_{\beta_{\gamma_{\tilde{f}_{\beta_{\gamma_{\tilde{f}}}}}}}}}}\ \text{and} \end{array}$
- Magnetized QGP in HIC: a spinless fluid or a magnet? The magnetic field induced phases and transports

• Uncertainty in magnetic field in heavy ion collisions

• Magnetized QGP in HIC: a spinless fluid or a magnet?

• Pense magnetized QED matter: paramagnet

• Polarization d Center field induced phases and transports

Center field induced phases and transports

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ald in heavy ion collisions

a spinless fluid or a magnet?

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	- Dense magnetized QED matter: paramagnet
- Dense & hot magnetized QCD matter: paramagnet Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST
	- Polarization dynamics in HIC
- Conclusion and outlook Conclusion and builder Fundamental Physics, AUST Center for Fundamental Physics, AUST

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Phases under magnetic field c field ϵ

Transport under magnetic field: chiral magnetic effect Chiral magnetic effect $J_{CME} = \frac{e^2}{2\pi^2} \mu_5 B$ CME measures topological fluctuation in quark-gluon plasma Kharzeev, McLerran, Warringa, NPA 2008 Cundamental Physics, AUST Center for Fundamental Physics, AUST Center for $\partial_{\mu}U_{\beta}^{\mu}=-\frac{g^2N_f}{16\pi^2}\text{Tr}\left[\epsilon^{\mu\nu\rho\sigma}G_{\mu\nu}G_{\rho\sigma}\right]$ CME measures topological fluctuation in quark-gluon plasma σ_{μ} $\sigma_{\$ Chiral magnetic effect $J_{\text{CME}} = \frac{e^2}{2\pi^2} \mu_5 B$

Warringa, NPA 2008

Content of Fundamental Warringa, NPA 2008

Content of Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics Transport under magnetic field: chiral magnetic effect

Chiral magnetic effec Transport under magnetic field: chiral magnetic effect

Marzeev, McLeran,

Warringa, NPA 2008

Marzee port under magnetic field: chiral magnetic effect

magnetic effect

Maringa, NPA 2008

M Center Fundamental Physics, Australian Physics, AUST Center Fundamental Physics, AUST Cen quertic field: chiral magnetic effect
 $MEE = \frac{e^2}{2\pi^2} \mu_5 B$

Kharzeev, McLerran,

Warringa, NPA 2008

Center Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center fo E_{L} Equal Physics, McLerran, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, Austral $\mathsf{rad}\ \overset{\frown}{\mathsf{m}}$ agnetic effect

Transport under magnetic field: chiral magnetic effect $\mathsf{rad}\ \overset{\frown}{\mathsf{m}}$ agnetic effect

7	Transport under magnetic field: chiral magnetic effect	
Chiral magnetic effect	$J_{\text{CME}} = \frac{e^2}{2\pi^2} \mu_5 B$	Li, Kharzeev, et al, Nature physics 2016?
0. $J_{\text{CME}} = -\frac{e^2}{16\pi^2} e^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma} \sim \mathbf{E} \cdot B$	Li, Kharzeev, et al, Nature physics 2016?	
0. $J_{\text{CME}} = -\frac{e^2}{16\pi^2} e^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma} \sim \mathbf{E} \cdot B$	Li, Kharzeev, et al, Nature physics 2016?	
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0. $\mu_5 = -\frac{e^2}{16\pi^2} e^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma} \sim \mathbf{E} \cdot B$	Li, Kharzeev, et al, Nature physics 2016?	
1. $\mu_5 = -\frac{e^2}{16\pi^2} e^{\mu\nu\rho\sigma} F_{\mu\nu$		

Magnetic field in Heavy ion Collisions Collisions Fundamental Physics, Australian Physics, Australian Physics, AUST Center for Fundamental Physics, A

Electric conductivity from Lattice & Experiment

What can QGP be other than conducting medium? ducting medium?

0th approx: spinless conducting fluid 1st approx: consisting of spinning particles, magnetized by B-field, like magnet an conducting medium?

Example in Fundamental Physics, Australian Physics, Austral

L. Dong, SL, 2403.12615

QGP as a paramagnet (weak B) $\text{weak } \mathsf{B)}$

Bali, Endrodi, Piemonte, JHEP 2020

QGP as a paramagnet (strong B) Center Fundament (strong B)
 $E = \sqrt{m^2 + p_3^2 + 2neB}$
 $n = 0$ lowest Landau level dominated
 $n = 0$ lowest Landau level dominated
 $n = 0$ lowest Landau level dominated
 $n = 0$ solver, Rischke, Vasak, $\frac{m}{2}$
 $\frac{m}{2}$
 CGP as a paramagnet (strong B)
 $E = \sqrt{m^2 + p_3^2 + 2neB}$
 $n = 0$ lowest Landau level dominated
 $n = 0$ lowest Landau level dominated
 $n = 0$ lowest Landau level dominated
 $\frac{Sovkov, Sukhabov, Sukhabov, Sukhabov, Sukhabov, regative charge\nnegative charge\nnegative charge\n*s_z*$ CGP as a paramagnet (strong B)

($\sqrt{m^2 + p_3^2 + 2neB}$

lowest Landau level dominated

e charge $s_z = 1/2$
 $s_z = -1/2$
 $s_z = \text{genet (strong B)}$
ated $\frac{C_{\text{S}}_{\text{S}}}{\sum_{\text{S}}_{\text{S}}$ Shops Pischko Vasak Sic $\mathsf{trop}_{\Theta}(\mathsf{B})$

$$
E=\sqrt{\stackrel{\wedge}{m}\stackrel{\wedge}{\leftrightarrow}\stackrel{\wedge}{p_3^2}+2neB}
$$

lowest Landau level dominated

positive charge

negative charge $s_z = -1/2$

Cundamental Physics, AUST Center for Fundamental Physics, AUST Center for

Gorbar, Miransky, Sovkovy, Sukhachov, JHEP 2017 SL, Yang, JHEP 2021 Center $s_z = 1/2$

Center Miransky, Sorbar, Miransky, Sorbar $E = \sqrt{m^2 + p_3^2 + 2neB}$
 $n = 0$ lowest Landau level dominated
 $n = 0$ lowest Landau level dominated
 $\begin{array}{ccc}\n\text{Mean, E5chke, Vasak/3/2, A} \\
\text{Mean, H5chke, Vasak/3/2}\n\end{array}$
 $\begin{array}{ccc}\n\text{Mean, E5chke, Vasak/3/2, A} \\
\text{Mean, M5chke, Vasak/3/2}\n\end{array}$
 $\begin{array}{ccc}\n\text$ $C_{e_{n_{\ell_{\ell_{\ell_{\ell}}}}}}$

Candau level dominated

Candau level dominated

Candau level dominated

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Center for Fundamental Physics, AUST Center for Fundamental Physics, A **paramagnet (strong B)**

vel dominated

Vel dominated

Center Sheng, Rischke, Vasak

Vang, EPJA 2017

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Center Strong Surfaction, Surfaction, Surfaction, AUST Center 2017

Strong JHEP 2021

Sheng, Rischke, Vasak,

Wang, EPJA 2017

magnetization from spin of LLL states **Center for Fundamental Physics, AUST Center for Fundamental Physics, AUS**

What if B turned off (strong B)? What if B turned off (strong B)?

Contribution of ELL states demagnetized $\tau_B \gg \tau_{rel}$

Equivalently: free relaxation of ELL states $\tau_B \ll \tau_{rel}$

momentum isotropization $\tau_{rel} \sim \frac{1}{g^4 T} \int_{\gamma_{rel}}^{\gamma_{rel}} \gamma_{rel} \sim \frac{1}{\sqrt{3}}$
 Mat if B turned off (strong B)?

baticaly: LLL states demagnetized $\tau_B \gg \tau_{rel}$

baticaly: free relaxation of LLL states $\tau_B \ll \tau_{rel}$

tum isotropization $\tau_{rel} \sim \frac{1}{g^4 T} \int_{\gamma_{\text{max}}}^{\gamma_{\text{max}}} \gamma_{\text{max}}$

GP remains a LLL s **Control of Fundamental Physics, AUST Center for Fundamental Physics, AUS** $\begin{array}{c} \displaystyle \text{off (strong B)?} \ \text{emagnetized} \hspace{0.5cm} \tau_B \gg \tau_{rel} \ \text{Ric} \sim \tau_{rel} \end{array}$ $\log B$ _{er for Fundamental Physics}, $\log B$

turned off adiabaticaly: LLL states demagnetized

turned off suddenly: free relaxation of LLL states Center of Fundamental Physics, AUST Center for Fundamental Physics, AUST Examples of Fundamental Physics, AUST Center for Fundamental Physics, AUS What if B turned off (strong B)?

turned off adiabaticaly: LLL states demagnetized $\tau_B \gg \tau_{rel}$

turned off suddenly: free relaxation of LLL states $\tau_B \ll \tau_{rel}$
 $\gamma_{rel} \sim \frac{1}{g^4 T} \gamma_{rel} \sim \frac{1}{g^4 T} \gamma_{rel} \sim \frac{1}{\gamma_{rel}}$

this

momentum isotropization

It is likely QGP remains a LLL state after rapid decay of B $\mathcal{L}_{\mathcal{L}_{\mathcal{S}}^{\mathcal{L}_{\mathcal{S}}}}$ It is likely QGP remains a LLL state after rapid decay of B
Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST AUST Center for Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST

Photon self-energy in massless QED under strong B Example 11 **Center of Center Strong B**

Symmetric anti-symmetric
 $\frac{q_0^2b^{\mu}b^{\nu}+q_0q_3u^{\{\mu}b^{\nu}\}}{q_0+i\epsilon)^2-q_3^2}+\frac{ie^2\mu}{2\pi^2}\left(q_0\epsilon^{\mu\nu\rho\sigma}+u^{\{\mu}\epsilon^{\nu\}}\lambda\rho\sigma q_x^T\right)u_{\rho}b_{\sigma}$

agnetic Wave in Hall effect: dri **Center Strong B**
 CENTER CENTER AUST CENTER AUST CENTER FOR FUNDAMENTAL PHYSICS, AUST CHAPTER FOR FUNDAMENTAL PRIMER FOR FUNDAMENTAL PRIMER FOR FUNDAMENTAL PRIMER FOR FUNDAMENTAL PRIMER FOR FUNDAMENTAL PHYSICS, AND THE ED under strong B

soft photon symmetric anti-symmetric soft photon symmetric anti-symmetric anti-symmetric anti-symmetric anti-symmetric anti-symmetric and symmetric $\Pi_R^{\mu\nu} = -\frac{e^3B}{2\pi^2} \frac{q_3^2u^{\mu}u^{\nu} + q_0^2b^{\mu}b^{\nu} + q_0q_3u^{\{h\}\nu^{\}}}{4(q_0 + i\epsilon)^2 - q_3^2} + \frac{i e^2 \mu}{2\pi^$ Photon self-energy in massless QED under strong B

soft photon symmetric
 $\Pi_R^{\mu\nu} = -\frac{e^3B}{2\pi^2} \frac{q_3^2y^{\mu}u^{\nu} + q_0^2b^{\mu}b^{\nu} + q_0q_3u^{(\mu}\nu^{\nu})}{4(q_0 + i\epsilon)^2 - q_3^2} + \frac{i e^2 u}{2\pi^2} \left(q_0 e^{\mu\nu\rho\sigma} + u^{[\mu}e^{\nu]\lambda\rho\sigma}q_{\lambda$ Photon self-energy in massless QED under strong B

of photon symmetric anti-symmetric anti-symmetric
 $\mu^{\mu} = -\frac{e^{3}B}{2\pi^{2}} \frac{q_{3}^{2}u^{\mu}u^{\nu} + q_{0}^{2}b^{\mu}b^{\nu} + q_{0}q_{3}u^{\mu}b^{\nu}}{q_{(q_{0} + i\epsilon)^{2} - q_{3}^{2}} + \frac{ie^{2}\mu}{2\pi^{$ The *Center Fundamental Physics, AUST Center for Fundamental Physics, AUS*

Chiral Magnetic Wave in lowest Landau level approx

> Kharzeev, Yee, PRD 2011 Fukushima PRD, 2011 Gao, Mo, SL, PRD 2020

 $u^{\mu} = (1,0,0,0)$ fluid $b^{\mu} = (0,0,0,1)$ B-field $u^{\mu} = (1,0,0,0)$ fluid
 $b^{\mu} = (0,0,0,1)$ B-field
 $b^{\mu} = (0,0,0,1)$ B-field
 $c^{\mu} = (0,0,0,1)$ B-field Chiral Magnetic Wave in

lowest Landau level approx
 $\begin{array}{ccc}\n\text{Kharzeev, Vee, PRD 2011}\n\text{Kharzeev, Vee, PRD 2011}\n\text{Kharzeev, Vee, PRD 2011}\n\text{Kharzeev, Vee, PRD 2012}\n\text{Kharzeev, Vee, PRD 2020}\n\text{Kharzeev, Vee, PRD 2020}\n\text{Kumg, PRD 2022}\n\text{Kumg, PRD 2022}\n\text{Var, Vee$

 $\mathbb{F}q^{\mu}$ photon momentum

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Hall effect: drift velocity + charge density \rightarrow current **CENTER AUST CENTER FOR CENTER EXECUTER AUTHOR AUTOMORER FOR AUSTRAL PHYSICS, AUST CENTER 2020**

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Hidaka, Fukushima, JHEP 2020 SL, Yang, JHEP 2021 Yang, PRD 2022

Photon dispersions in massless QED under strong B $\begin{aligned} \mathsf{less QED}\ \text{under strong B} \ \cdot -i\int d^4y \Pi^{\mu\nu}_{a r}(x,y) A_{\nu}^{\text{max}} \ & \cdot -i\int d^4y \Pi^{\mu\nu}_{a r}(x,y) A_{\nu}^{\text{max}} \ & \times \int d^4y \Pi^{\mu\nu}_{a r}(x,y) A_{\nu}^{\text{max}} \ & \times \int d^4y \Pi^{\mu\nu}_{a r}(x,y) A_{\nu}^{\text{max}} \end{aligned}$ ED under strong B

$$
\left\langle \!\!{\,}^{\mathop{}\limits_{}}_{\mathop{}\limits^{}}\right. \! \partial_{\mu}^{\mu} \mu - \partial^{\mu} \partial^{\nu} \big) \, A_{\nu,r} = j^\mu_r = -i \, \int d^4 y \Pi^{\mu\nu}_{ar}(x,y) A_{\nu,r}
$$

 $q_0^2 = \tilde{B} + q^2$ gapped mode

low-energy modes

$$
q_0^2 = \tilde{B} + q^2
$$
 gapped mode
\n
$$
q_0^2 = \frac{1}{2} \left(\tilde{\mu}^2 + q_\perp^2 + 2q_3^2 + \sqrt{4\tilde{\mu}^2 q_3^2 + (q_\perp^2 + \tilde{\mu}^2)^2} \right) = x_\perp^2,
$$
\n
$$
\tilde{\mu} = e^2 \mu / 2\pi^2
$$
 $\tilde{B} = e^3 B / 2\pi^2$ $q_\perp^2 = q_\perp^2 + q_\perp^2 + 2q_3^2 + \sqrt{4\tilde{\mu}^2 q_3^2 + (q_\perp^2 + \tilde{\mu}^2)^2} \right) = x_\perp^2,$ \n
$$
\tilde{\mu} = e^2 \mu / 2\pi^2
$$
 $\tilde{B} = e^3 B / 2\pi^2$ $q_\perp^2 = q_\perp^2 + q_\perp^2$ $q_\perp^2 = q_\$

medium Fermi liquid-like rather than fluid-like $\tilde{\mu} = e^2 \mu / 2\pi^2$ $\tilde{B} = e^3 B / 2\pi^2$ $q_1^2 = q_1^2 + q_2^2$
 $\tilde{\mu} = e^2 \mu / 2\pi^2$ $\tilde{B} = e^3 B / 2\pi^2$ $q_1^2 = q_1^2 + q_2^2$

L. Dong, SL, 2403.12615 $F_{U_1}_{\cap_{U_1}}$ F_{U_2}

 $q_0^2 = q^2$ free

LLL

Photon polarization in massless QED under strong B **n** massless QED under strong B
 $\tilde{u} \sim e^2 \mu \gg q$
 $\tilde{u} \sim \frac{A_2}{A_0} = -\frac{i(q_1q - iq_2\overline{q}_3)}{q_1^2q} \tilde{u}, \quad \frac{A_3}{A_0} = \frac{q_3}{|q_3|q} \tilde{\mu}.$
 $q_{\perp} \circ_{\phi_1} \frac{A_1}{A_2} \simeq -i$
 $q_{\perp} \circ_{\phi_2} \frac{A_1}{A_2} \simeq -i$ Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST ED under strong B

Hall dynamics requires

$$
q_0, q \sim \tau_R^{-1} \sim e^4 \mu \qquad \qquad \tilde{\mu} \sim e^2 \mu \gg q
$$

simple interpretation at $q_3 \gg q_{\perp}$

One photon polarization favored due to interaction with spin polarized CMW in charged magnetized medium Center of Fundamental Physics, AUST Center for Fundamental Physics, AUST C $\frac{C_1}{C_2}$

Center Fundamental Physics AUST Center for Fundamental Physics, Australian Australian Australian Physics, AUST Center action with spin polarized medium

Center for Fundamental Physics, AUST Center for Funda Hall dynamics requires
 $q_0, q \sim \tau_R^{-1} \sim e^4 \mu$
 $\tilde{\mu} \sim e^2 \mu \gg q$
 $\tilde{\mu} \sim e^2 \mu \gg q$
 $\tilde{\mu} \sim \frac{e^2 \mu}{\sqrt{2}} \approx \frac{1}{\sqrt{2}}$
 $\tilde{\mu} \sim \frac{43}{\sqrt{2}} = -\frac{i(q_1q - iq_2|q_3)}{q_1^2q} \tilde{\mu},$
 $\tilde{A}_0 = \frac{q_3}{|q_3|q} \tilde{\mu}.$
 $\tilde{A}_$ Photon polarization in massless QED under strong B

Hall dynamics requires
 $q_0, q \sim \tau_R^{-1} \sim e^2 \mu$ $\mu \sim e^2 \mu \gg q$
 $\frac{q_0}{\sqrt{2\pi}} = x_1^2 : \frac{A_1}{A_0} = \frac{i(q_2q + iq_1|q_3|)}{q_1^2q} \bar{\mu}, \quad \frac{A_2}{A_0} = -\frac{i(q_1q - iq_2|q_3|)}{q_1^2q}$ Photon polarization in massless QED under strong B

Hall dynamics requires
 $\hat{\mu} \sim e^2 \mu \gg q$
 $\hat{\mu}_0 \sim e^2 \mu \gg q$
 $q_0^2 = x_1^2 : \frac{A_1}{A_0} = \frac{i(q_2q + iq_1|q_3)}{q_1^2q} \hat{\mu}_1$, $\frac{A_2}{A_0} = -\frac{i(q_1q - iq_2|q_3)}{q_1^2q} \hat{\mu}_1$, **Contract of The Physics AUST Center for Fundamental Physics, AUST Center** Example 1 **Center Strong B**
 $\tilde{\mu} \sim e^2 \mu \gg q$
 $\tilde{\mu} \sim e^2 \mu \gg q$
 $\frac{4a}{q_1^2 q} = -\frac{i(q_1 q - iq_2 q_3)}{q_1^2 q} \tilde{\mu}, \quad \frac{A_3}{A_0} = \frac{q_3}{|q_3|q} \tilde{\mu}.$
 $\tilde{\mu} \approx q_1 \cdot c_{\infty} \frac{A_1}{A_2} \approx -i$

Little Direction polarization fa

$\frac{1}{2}$ Self-energy of unpolarized massless probe fermion c ss probe fermion

Implication for polarization dynamics Center for Fundamics

Center for Fundamental Physics, AUST Center for Fund Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST dynamics

Implication for polarization dynamics\n
$$
\Gamma_L \simeq \frac{exp_3}{p} = \frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3),
$$
\n
$$
\Gamma_R \simeq -\frac{exp_3}{p} = \frac{-e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
$$
\n
$$
\Gamma_R \simeq -\frac{exp_3}{p} = \frac{-\frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
$$
\n
$$
\frac{exp_3}{2} = \frac{-\frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
$$
\n
$$
\frac{exp_3}{2} = \frac{-\frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
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\n
$$
\frac{exp_3}{2} = \frac{-\frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
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$$
\frac{exp_3}{2} = \frac{-\frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
$$
\n
$$
\frac{exp_3}{2} = \frac{-\frac{e^2 T q_{UV}^2}{8 \pi \tilde{\mu}p} \epsilon(p_3).
$$
\n
$$
\frac{exp_3}{2} = \frac{2}{\tilde{\mu}p} \epsilon(p_3).
$$
\n
$$
\frac{exp_3}{2} = \frac{2}{\tilde{\mu}p}
$$

amplified modes: right-handed $p_3 > 0$ left-handed

Positive spin polarization along B

charged magnetized QED medium behaves like paramagnet in dynamical sense Charged magnetized QED medium behaves like paramagnet in dynamical sense in $\frac{G_{\gamma_{16}}}{G_{\gamma_{16}}}\approx 4U_{\gamma}$
Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Ce Content for Fundamental Physics, AUST Center Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Sense of Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundame Implication for polarization dynamics
 $\frac{2}{p} \frac{c_3p_3}{\overline{p}_3} = \frac{e^2 T q_{\text{UV}}^2}{8\pi \overline{\mu}p} \epsilon(p_3),$
 $\frac{c_3p_3}{p} = \frac{2}{\overline{\epsilon}^2 T q_{\text{UV}}^2} \epsilon(p_3).$

fied modes:

anded $p_3 > 0$ Positive spin polarization along B_{anded} Centron for polarization dynamics
 $\frac{\frac{2^2Tq_{UV}^2}{8\pi\bar{\mu}p} \epsilon(p_3)}{8\pi\bar{\mu}p}$,
 $\frac{\frac{2^2Tq_{UV}^2}{8\pi\bar{\mu}p} \epsilon(p_3)}{8\pi\bar{\mu}p}$,

s:
 $\frac{3>0}{3<0}$ Positive spin polarization along B

etized QED medium behaves like param

Gluon self-energy in massless QCD under strong B D under strong B

soft gluon

CMW in LLL approx $u^{\mu} = (1,0,0,0)$ fluid $b^{\mu} = (0,0,0,1)$ B-field $\sqrt{q^{\mu}}$ gluon momentum chromo-Hall effect: balance between chrome-electric gluon self-interaction entitled and Lorentz force Cundamental Physics, AUST Center for Fundamental Physics, AUST Center for $u^{\mu} = (1,0,0,0)$ fluid
 $u^{\mu} = (1,0,0,0)$ fluid
 $u^{\mu} = (0,0,0,1)$ B-field
 $u^{\mu} = (0,0,0,1)$ B-field
 $u^{\mu} = (0,0,0,1)$ B-field
 $u^{\mu} = (0,0,0,1)$ B-field
 $u^{\mu} = -2m^2(x^2 - 1)(1 - xQ_0(x)),$
 $u^{\mu} = (0,0,0,1)$ B-field
 u^{μ} Center $\frac{1}{2}\pi^2$ $(q_0 + ie)^2 - q_3^2$ $2\pi^2 2$
 $3\pi^2 2$
 $3\pi^2 2\pi^2 2$

conter force and Lorentz soft gluon²

CMW in LLL approx

C_{enter} Fundamental Physics, Australian Fundamental Physics, Australian Fundamental Physics, Australian Fundamental Physics, Austral Physics, Australian Fundamental Physics, Australian F CHEND Self-energy in massless QCD under strong B

soft gluon

CMW in LLL approx

Common Physics, Australian

Physics, Australian Fundamental Phys Center Fundamental Physics ACD under strong B

oft gluon

CMW in LLL approx
 $\Pi_R^{u\mu,AB} = \left[-\frac{g^2 e B}{2\pi^2} \frac{g_3^2 u^u u^v + g_0^2 b^u b^v + q_0 g_3 u^u b^v}{(q_0 + i\epsilon)^2 - q_3^2} + \frac{g_3^2}{2\pi^2} \frac{u}{2} \left(q_0 e^{\mu\nu\rho\sigma} + u^{[\mu}e^{\nu]\lambda\rho\sigma$ **CENTE AUST CENTE AUTOR CENTE AUTHRETICS**

CENTER FOR CENTE FOR THE AUTHOR CONTROL CENTER FOR THE AUSTRALISM CONTROL CENTER FOR THE FUNDAMENTAL AUG.
 $-\frac{g^2eB}{2\pi^2}\frac{q_3^2u^{\mu}u^{\nu}+q_0^2b^{\mu}b^{\nu}+q_0q_3u^{\mu}b^{\nu}}{q_0+i$ mergy in massless QCD under strong B

W in LLL approx
 $\frac{2}{3}u^{\mu}u^{\nu} + q_0^2b^{\mu}b^{\nu} + q_0q_3u^{(\mu}b^{\nu})^2 \otimes iq^2\mu}{(q_0 + i\epsilon)^2 - q_3^2} + \frac{2}{2\pi^2} \frac{2}{2} \left(q_0 \epsilon^{\mu\nu\rho\sigma} + u^{[\mu} \epsilon^{\nu]\lambda\rho\sigma} q_{\lambda}^T \right)^2 \hat{u}_{\rho} b_{\sigma}$
 δ^{AB **CENTER CENTER FOR FUNDAMENTAL PHYSICS CENTER (AUTOR FUNDAMENTAL PHYSICS)**
 $\frac{b^{\mu}b^{\nu} + q_0q_3u^{\{\mu}b^{\nu}\}}}{i\epsilon)^2 - q_3^2} + \frac{i g^2}{2\pi^2} \frac{\mu}{2} \left(q_0 \epsilon^{\mu\nu\rho\sigma} + u^{[\mu} \epsilon^{\nu]\lambda\rho\sigma} q_{\lambda}^T \right)^{\nu} u_{\rho} b_{\sigma}}$

chromo-Hall effe $\begin{CD} \mathsf{ess}\ \mathsf{QCD}\ \mathsf{under}\ \mathsf{strong}\ \mathsf{B} \ \begin{CD} \ \frac{C_{\mathsf{e}}}{\sqrt{\gamma_{\mathsf{e}}}} \end{CD} \end{CD}$

Two limits of QGP medium ${\sf dim}\hat{\bf m}_{{\bf r}_{\odot,{\bf r}_{\rm eff}}}$

density dominate $\bar{\mu}^2 \gg \Pi_{T/L}$ medium like Fermi-liquid Center dominate $\bar{\mu}^2 \gg \Pi_{T/L}$ medium like Fermi-liquid

temperature dominate $\bar{\mu}^2 \ll \Pi_{T/L}$, medium like fluid η_{S}
 $\bar{\mu} \sim g^2 \mu$, $\Pi_{T/L} \approx g^2 T^2$
 $\bar{\mu} \sim g^2 \mu$, $\Pi_{T/L} \approx g^2 T^2$
 η_{S}
 η_{S}
 $\Pi_R^{\mu\nu,AB} = \left[\frac{2\pi^2}{2\pi^2} \frac{q^2eB}{(q_0 + ie)^2 - q_3^2} + \frac{iq^2}{2\pi^2} \frac{\mu}{2} \left(q_0 e^{\mu\nu\rho\sigma} + u^{[i}\psi] \right) \rho_{\sigma}$
 $-P_T^{\mu\nu} \Pi_T - P_L^{\mu\nu} \Pi_L \right] \delta^{AB}_{\psi}$
 ϕ_{σ}
 CEP medium

Content Physics (AUST Center For Fundamental Physics)
 $\Pi_R^{\mu\nu AB} = \left[-\frac{g^2 e B}{2\pi^2} \frac{g_3^2 u^{\mu} u^{\nu} + g_0^2 b^{\mu} b^{\nu} + g_0 g_3 u^{(\mu} b^{\nu})}{(q_0 + i\epsilon)^2 - q_3^2} + \frac{i g^2}{2\pi^2} \frac{\mu}{2} \left(q_0 \epsilon^{\mu\nu\rho\sigma} + u^{[\mu} \epsilon^{\mu] \$ **CEP medium**
 $\lim_{\mu\nu\wedge B} \int_{R} \frac{1}{2\pi^2} \left[\frac{g^2 e B}{2\pi^2} \frac{g_3^2 u^{\mu} u^{\nu} + g_0^2 b^{\mu} b^{\nu} + q_0 q_3 u^{\mu} b^{\nu}}{(q_0 + i\epsilon)^2 - q_3^2} + \frac{i g^2 \mu}{2\pi^2} \frac{\mu}{2} \left(q_0 e^{\mu\nu\rho\sigma} + u^{[\mu} e^{\mu} e^{\lambda\rho\sigma} q_3^{\nu}\right) u_{\rho} b_{\sigma} \right]$
 $\left. P_T^$ Two limits of QGP medium
 $\frac{2e}{2\pi^2} \frac{q^2e}{q^2} \frac{q^2y^{\mu}u^{\nu} + q_0^2y^{\mu}b^{\nu} + q_0qau^{(\mu}b^{\nu})}{(q_0 + ie)^2 - q_3^2} + \frac{iq^2}{2\pi^2} \frac{\mu}{2} \left(q_0 e^{\mu\nu\rho\sigma} + u^{(\mu}e^{\mu})^{\lambda\rho\sigma} q_3^{\mathrm{T}} \right) u_{\rho} b_{\sigma}$
 $P_L^{\mu\nu}\Pi_L \bigg] \delta^{AB}_{\sigma}$
 Center for Fundamental Physics, AUST Center for Fundamental Physics, AUS Note that $\frac{b^{\nu} + q_0 q_3 u^{\{\mu} b^{\nu}\}}{(\epsilon)^2 - q_3^2} + \frac{ig^2}{2\pi^2} \frac{\mu}{2} \left(q_0 \epsilon^{\mu\nu\rho\sigma} + u^{\{\mu} \epsilon^{\nu\}} \lambda^{\rho\sigma} q_4^T \right) u_{\rho} b_{\sigma}$
 $\Pi_{T/L}$ medium like Fermi-liquid
 $\Pi_{T/L}$ medium like fund $\eta_{\beta_{T/L}}$ and $\Pi_{T/L}$ med $\frac{(-\mu_b \nu_B)^2}{(4\mu_b \nu_B)^2} + \frac{ig^2}{2\pi^2} \frac{\mu}{2} \left(q_0 \epsilon^{\mu\nu\rho\sigma} + u^{[\mu_e \nu]\lambda\rho\sigma} q_\lambda^T \right) u_\rho b_\sigma$

temperature dominate $\bar{\mu}^2 \ll \Pi_{T/L}$ medium like fluid

 $\mu \sim g \mu, \quad \text{Irr}/L \approx g \mu$

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Density dominated limit $\mathsf{mit}^{\mathsf{C}_{\mathsf{C}}_{\mathsf{N}_{\mathsf{C}}}}$

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similar to QED case

damping from scattering with CMW states

$$
q_0,\, q \sim \tau_R^{-1} \sim g^4 \mu \ll \bar{\mu}.
$$

$$
\Gamma_L \simeq \frac{N_c^2 - 1}{2N_c} \frac{g^2 T q_{\text{UV}}^2}{8\pi \bar{\mu}p} \epsilon(p_3),
$$

\n
$$
\Gamma_R \simeq -\frac{N_c^2 - 1}{2N_c} \frac{g^2 T q_{\text{UV}}^2}{8\pi \bar{\mu}p} \epsilon(p_3).
$$

charged magnetized QGP in density dominated limit behaves like paramagnet in dynamical sense Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST With CMW states C_{C}
 $\Gamma_L \simeq \frac{N_c^2 - 1}{2N_c} \frac{g^2 T q_{\text{UV}}^2}{8 \pi \bar{\mu} p} \epsilon(p_3),$
 $\Gamma_R \simeq -\frac{N_c^2 - 1}{2N_c} \frac{g^2 T q_{\text{UV}}^2}{8 \pi \bar{\mu} p} \epsilon(p_3).$
 $\Gamma_R \simeq -\frac{N_c^2 - 1}{2N_c} \frac{g^2 T q_{\text{UV}}^2}{8 \pi \bar{\mu} p} \epsilon(p_3).$
 $\Gamma_R \simeq -\frac{N_c^$ Density dominated limit $\begin{aligned}\n\hat{Q} &= -2i\pi \epsilon(q_0) \left(\frac{1}{2} + f_g(q_0)\right) \left(\frac{\delta(q_0^2 - \bar{x}_1^2)}{q_0^2 - \bar{x}_2^2} + \frac{\delta(q_0^2 - \bar{x}_2^2)}{q_0^2 - \bar{x}_1^2}\right) A_{\mu\nu}(Q)\bar{\mu}. \\
\hat{\mu} &= -2i\pi \epsilon(q_0) \left(\frac{1}{2} + f_g(q_0)\right) \left(\frac{\delta(q_0^2 - \bar{x}_1^2)}{q_0^2 - \bar$ Central Density dominated limit $\epsilon(q_0) \left(\frac{1}{2} + f_g(q_0)\right) \left(\frac{\delta(q_0^2 - \bar{x}_1^2)}{q_0^2 - \bar{x}_2^2} + \frac{\delta(q_0^2 - \bar{x}_2^2)}{q_0^2 - \bar{x}_1^2}\right) A_{\mu\nu}(Q) \bar{p}_1$

Case damping from scattering
 $g^4 \mu \ll \bar{\mu}$.
 $g^4 \mu \ll \bar{\mu}$.
 $\frac{q_{\text{UV}}$

Temperature dominated limit \dim it ϵ

Temperature dominated limit
\n
$$
D_{\mu\nu}^{rr,A}(Q) = 2i \text{Im} \left[\frac{Q^2 q^2}{(Q^2 - \Pi_T) (q^2 Q^2 (q_0^3 - q_3^2) - Q^2 q_3^2 \Pi_T - q_0^2 q_\perp^2 \Pi_L)} \right] \left(\frac{1}{2} + f_g(q_0) \right) A_{\mu\nu} \bar{\mu}.
$$
\n
$$
q_0, q \sim \tau_R^{-1} \sim g^4 T^4/\epsilon_{\text{cyl}} \text{ damping from scattering with gluons}
$$
\n
$$
T_{\hat{L}} \approx -\epsilon(p_3) \left(H_2 - \frac{|p_3|H_1}{p} \right),
$$
\n
$$
\Gamma_R \simeq \epsilon(p_3) \left(H_2 - \frac{|p_3|H_1}{p} \right).
$$
\n
$$
H_i \sim \int dq h_i \implies H_1 \gg H_2
$$
\n
$$
q_0, q_1 \sim \tau_R^{-1} \sim g^4 T^4/\epsilon_{\text{cyl}} \text{ damping from scattering with gluons}
$$
\n
$$
\gamma_{\text{cyl}} \sim \tau_{\text{cyl}} \sim \tau_{\
$$

Implication for polarization dynamics in HIC amics in HIC $\mathsf{C}_{\mathsf{A}\mathsf{B}}$

- Low energy HIC produces medium with baryonic and electric charge
- Initial magnetic field decays quickly and magnetizes QGP
- Magnetized QGP continues to polarize quarks produced at later stage like strange quark, effectively extend life time of B ϵ Magnetized QGP continues to polarize quarks produced at later
stage like strange quark, effectively extend life time of B
AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Funda Center Fundamental Physics, AUST Center Fundamental Physics, AUST Center for Fundamental Physics, AUST Center Center Fundamental Physics, AUST Center Fundamental Physics, AUST Center Fundamental Physics, AUST Center for Center For Fundamental Physics, AUST Center for Fundamental Physics, AUST

Conclusion

Center for Fundamental Physics,

- Splitting of damping rate of spin component of probe fermion in charged magnetized QED matter • Splitting of damping rate of spin component of probe fermion in

charged magnetized QED matter

• Splitting of damping rate of spin component of probe quark in

• Paramagnet charged QCD matter

• Paramagnet charged QCP c Conclusion

Splitting of damping rate of spin component of probe fermion in

charged magnetized QED matter

Splitting of damping rate of spin component of probe equark in

Subsequent appearance of Center for Fundamental Au Conclusion

Splitting of damping rate of spin component of probe fermion in

charged magnetized QED matter

Splitting of damping rate of spin component of probe quark in

Center for Fundamental Physics, AUST Center for Fun Example of the dimping rate of spin component of probe fermion in a dimagnetized QED matter agnet charged QCD matter agnet charged QCP can polarize probe quark in a dimagnetized QCD matter agnet charged QCP can polarize pr $\frac{C_{\text{avg}}}{\text{avg}}$ $\frac{A}{\text{C}}$ Conclusion
 $\frac{B}{\text{avg}}$ and $\frac{C_{\text{avg}}}{\text{avg}}$ and $\frac{C_{\text{avg}}}{\text{avg}}$ center $\frac{C_{\text{avg}}}{\text{avg}}$
 $\frac{C_{\text{avg}}}{\text{avg}}$ $\frac{C_{\text{avg}}}{\text{avg}}$
 $\frac{C_{\text{avg}}}{\text{avg}}$ $\frac{A_{\text{avg}}}{\text{avg}}$
 $\frac{A_{\text{avg}}}{\$ Conclusion

of spin component of probe fermion in $\frac{C_{\text{S}}}{\sqrt{\frac{C_{\text{S}}}{C_{\text{S}}}}}}$ of spin component of probe quark in

matter $\frac{C_{\text{S}}}{\sqrt{\frac{C_{\text{S}}}{C_{\text{S}}}}}}$ can polarize probe quark $\frac{C_{\text{S}}}{\sqrt{\frac{C_{\text{S}}}{C_{\text{$ ν
 ν
	- Splitting of damping rate of spin component of probe quark in charged magnetized QCD matter
- Paramagnet charged QGP can polarize probe quark Center Fundamental Physics, AUST Center Fundamental Physi

Beyond strong B field limit

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 Beyond probe limit, backreaction to paramagnet $\begin{array}{cccccccccccccc} \text{OutIO.} \end{array}$ + Beyond strong B field limit
 $\begin{array}{cccccccccc} \text{Heyond strong B field limit} \end{array}$
 $\begin{array}{cccccccccc} \text{Heyond probe limit, backreaction to paramagnetic} \end{array}$

Thank you! Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST

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