Spin Polarization of Photons from Axially Charged Plasma

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Based on

"Spin Polarized Photons and Dileptons from Axially Charged Plasma", KM and Ho-Ung Yee, Phys.Rev. D88,(2013)114029 (arXiv:1307.8099)

"Spin Polarized Photons from Axially Charged Plasma at Weak Coupling: Complete Leading Order", KM and Ho-Ung Yee, Phys.Rev. D93,(2016)065053 (arXiv:1512.01316)

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1. Introduction
2. Spin polarized thermal photons from axially charged plasma at weak coupling (pQCD)
   - Hard "leading log" and "constant under the log" contributions of Compton scattering and pair annihilation

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3. Spin polarized thermal photons from axially charged plasma at strong coupling (AdS/CFT)

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Introduction

Axial Charge is P- and CP-odd

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$$\psi_L \rightarrow q_L\ (\text{quark}),\ \bar{q}_R\ (\text{anti}-\text{quark})$$
$$\psi_R \rightarrow q_R\ (\text{quark}),\ \bar{q}_L\ (\text{anti}-\text{quark})$$

$$P\ :\ q_L \longleftrightarrow q_R\,,\ \bar{q}_L \longleftrightarrow \bar{q}_R$$
$$C\ :\ q_L \longleftrightarrow \bar{q}_L\,,\ q_R \longleftrightarrow \bar{q}_R$$

Axial Charge

$$J_A^0 = N(q_L) + N(\bar{q}_L) - N(q_R) - N(\bar{q}_R)$$

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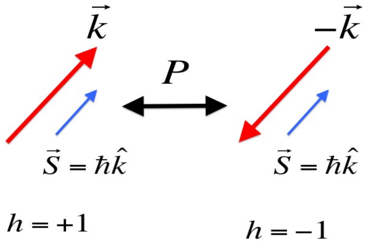
  1. clean isolation and no (easy) background effects
  2. unambiguous signal of axial charge and triangle anomaly

Photons



Spin polarization (helicity h) is P-odd

$$\epsilon^\mu_\pm = \frac{1}{\sqrt{2}}(0, 1, \pm i, 0)\,, \quad \vec{k} = k\hat{x}^3$$

Introduction

- the "circular polarization asymmetry" $A_{\pm\gamma}$ of photons

$$A_{\pm\gamma} \equiv \frac{\frac{d\Gamma}{d^3\vec{k}}(\epsilon_+) - \frac{d\Gamma}{d^3\vec{k}}(\epsilon_-)}{\frac{d\Gamma}{d^3\vec{k}}(\epsilon_+) + \frac{d\Gamma}{d^3\vec{k}}(\epsilon_-)} = \frac{\mathrm{Im}\,\sigma_\chi(k^0)}{\mathrm{Re}\,\sigma_{11}(k^0)} \propto \mu_A$$

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  is P- and CP-odd observable
- since, the total photon emission rate has already been computed by AMY in pQCD, we only need to compute the "P-odd photon emission rate"

$$\frac{d\Gamma^{\mathrm{odd}}}{d^3k} = \frac{d\Gamma}{d^3\vec{k}}(\epsilon_+) - \frac{d\Gamma}{d^3\vec{k}}(\epsilon_-)$$

  in pQCD and AdS/CFT

Introduction

- the thermal photon emission rate is given by the retarded correlation function of the electromagnetic current operator J_i in momentum space

$$G^R_{ij}(k) = (-i)\int d^4x\ e^{-ikx}\theta(x^0)\langle[J_i(x), J_j(0)]\rangle$$

as

$$\frac{d\Gamma^{\pm}}{d^3k} = \frac{e^2}{(2\pi)^3 2\omega} n_B(\omega)(-2)\mathrm{Im}\left[(\epsilon^{\mu}_{\pm})^* \epsilon^{\nu}_{\pm} G^R_{\mu\nu}\right]$$

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- the P-odd photon emission rate

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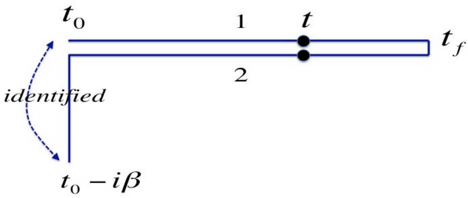
- then, the P-odd photon emission rate in "ra"-variables becomes

$$\frac{d\Gamma^{\rm odd}}{d^3k} \equiv \frac{d\Gamma^{+}}{d^3k} - \frac{d\Gamma^{-}}{d^3k} = \frac{e^2}{(2\pi)^3 2\omega} n_B(\omega)(-4)\,\mathrm{Im}\,G^{ra}_{12}(k)$$



- by placing operators in suitable positions in the two contours, one can generate all kinds of time orderings for correlation functions of

$$\mathcal{O}_r = \frac{1}{2}(\mathcal{O}_1 + \mathcal{O}_2) , \quad \mathcal{O}_a = \mathcal{O}_1 - \mathcal{O}_2$$

Spin polarized thermal photons from axially charged plasma at weak coupling (pQCD)

- the total thermal photon emission rate at weak coupling in pQCD (AMY)

$$(2\pi)^3 \frac{d\Gamma^{\text{total}}_{\text{LO}}}{d^3k} \approx \mathcal{A}(\omega)\Big(\log\left(T/m_f\right) + C^{\text{total},(0)}_{2\leftrightarrow 2}(\omega/T)$$

$$+ C^{\text{total},(0)}_{\text{LPM}}(\omega/T)\Big) + \mathcal{O}(\mu_A^2)$$

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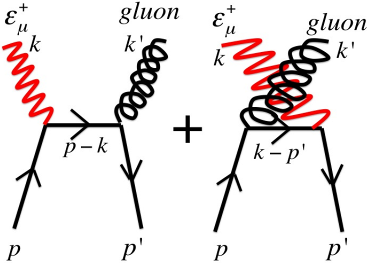
- in contrast, the P-odd photon emission rate at weak coupling in pQCD

$$(2\pi)^3 \frac{d\Gamma^{\rm odd}_{\rm LO}}{d^3k} \approx \mathcal{A}(\omega)\Big(C^{{\rm odd},(1)}_{\rm Log}(\omega/T)\log\left(T/m_f\right) + C^{{\rm odd},(1)}_{2\leftrightarrow 2}(\omega/T) + C^{{\rm odd},(1)}_{\rm LPM}(\omega/T)\Big)\frac{\mu_A}{T} + \mathcal{O}(\mu_A^3)$$

Hard "leading log" and "constant under the log" contribution of pair annihilation



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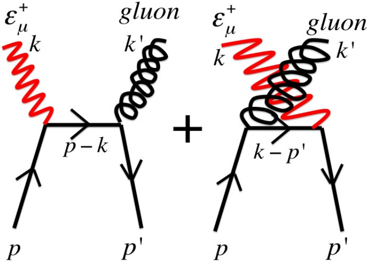
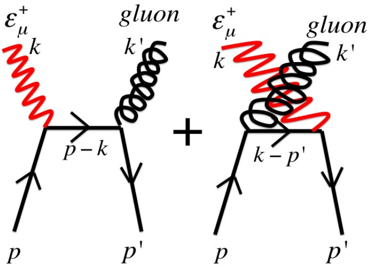


$$(2\pi)^3 \frac{d\Gamma^{\rm odd}_{hard}}{d^3k} = \frac{e^2 g^2 (N_c^2-1)}{4\omega} \int_p \int_{p'} \int_{k'} |\mathcal{M}^{\rm pair}(\epsilon_+)|^2 - |\mathcal{M}^{\rm pair}(\epsilon_-)|^2$$
$$\times \; n_+(|p|) n_-(|p'|)(1 + n_B(|k'|))(2\pi)^4 \delta(p + p' - k - k')$$

Hard "leading log" and "constant under the log" contribution of pair annihilation



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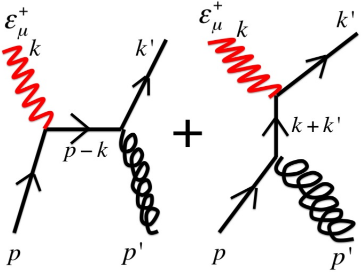
where

$$|\mathcal{M}^{\mathrm{pair}}(\epsilon_+)|^2 - |\mathcal{M}^{\mathrm{pair}}(\epsilon_-)|^2 = 4(t-u)\left(\frac{1}{t} + \frac{1}{u} - 2\left(\frac{p_\perp}{t} - \frac{p'_\perp}{u}\right)^2\right)$$

Hard "leading log" and "constant under the log" contribution of Compton scattering



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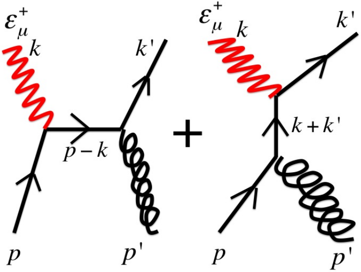

$$(2\pi)^3 \frac{d\Gamma^{\rm odd}_{hard}}{d^3k} = \frac{e^2 g^2 (N_c^2-1)}{4\omega} \int_p \int_{p'} \int_{k'} |\mathcal{M}^{\rm Comp}(\epsilon_+)|^2 - |\mathcal{M}^{\rm Comp}(\epsilon_-)|^2$$
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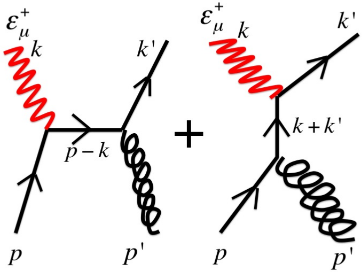
Hard "leading log" and "constant under the log" contribution of Compton scattering



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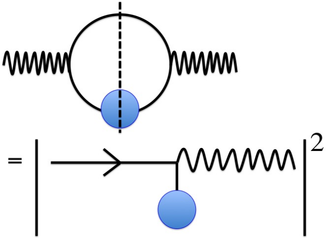
where

$$|\mathcal{M}^{\mathrm{Comp}}(\epsilon_+)|^2 - |\mathcal{M}^{\mathrm{Comp}}(\epsilon_-)|^2 = 4(s-t)\left(\frac{1}{t} + \frac{1}{s} - 2\left(\frac{p_\perp}{t} + \frac{k'_\perp}{s}\right)^2\right)$$

Soft contribution



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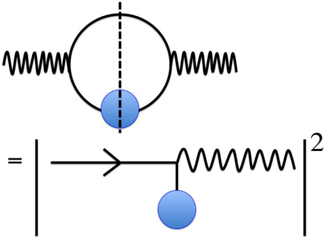
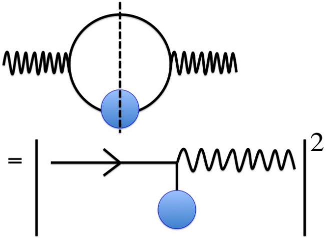


$$\frac{d\Gamma^{\mathrm{odd}}_{soft}}{d^3k} = \frac{e^2}{(2\pi)^3 2\omega} n_B(\omega)(-4)\mathrm{Im}\, G^{ra}_{12(soft)}(k)$$

Soft contribution



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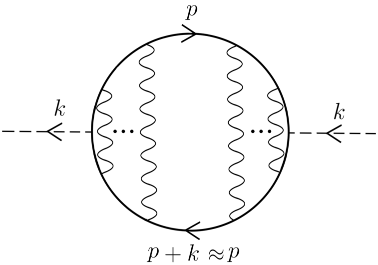
where

$$G^{ra}_{\mu\nu(soft)}(k) = \frac{d_R}{2}\int_p \text{tr}\left[\sigma^\nu \rho_F(p)\sigma^\mu \rho_F(p+k)\right]\left(n_+(p^0) - n_+(p^0+\omega)\right)$$

Collinear bremstrahlung and annihilation (LPM) contributions



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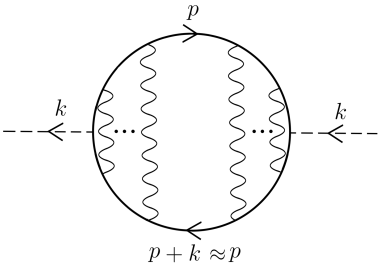

$$\frac{d\Gamma^{\mathrm{odd}}_{LPM}}{d^3k} = \frac{e^2}{(2\pi)^3 2\omega} n_B(\omega)(-4)\mathrm{Im}\, G^{ra}_{12(LPM)}(k)$$

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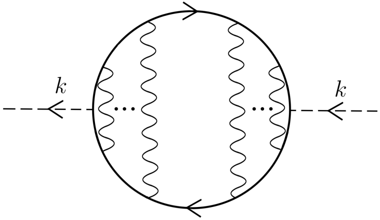

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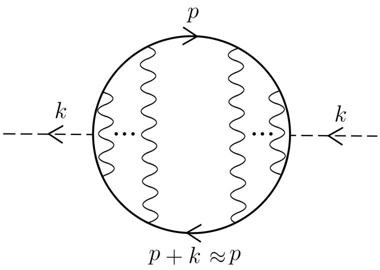
where

$$G^{ra}_{ij(LPM)}(k) \approx d_R \int \frac{d^4p}{(2\pi)^4} \left(n_+(p^0+\omega) - n_+(p^0)\right) \mathrm{tr}\left[S^{ra}(p+k)\sigma^j S^{ar}(p)\Lambda^i(p,k)\right]$$

Collinear bremstrahlung and annihilation (LPM) contributions



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and

$$\Lambda^i(p,k) = \sigma^i + (ig)^2 C_2(R) \int \frac{d^4Q}{(2\pi)^4} \sigma^\beta S^{ar}(p+Q)\Lambda^i(p+Q,k) S^{ra}(p+Q+k)\sigma^\alpha \mathcal{G}^{rr}_{\alpha\beta}(Q)$$

Collinear bremstrahlung and annihilation (LPM) contributions

$$G^{ra}_{12(LPM)}(k) = -\frac{d_R}{4}\int \frac{dp_{\|}\, d^2 p_{\perp}}{(2\pi)^3}\left(n_+(p_{\|}+\omega) - n_+(p_{\|})\right)\frac{|k|(2p_{\|}+|k|)}{p_{\|}^2(p_{\|}+|k|)^2}(p_{\perp}\cdot f_{\perp})$$

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where

$$\frac{\omega}{2p_(p_{+}\omega)}\left(-\partial_b^2 - \frac{3}{b}\partial_b + m_f^2\right)\, f(b) = i\,\mathcal{C}(b)\,f(b)$$

$$f_{\perp}^{i}(b) = \int \frac{d^2p_{\perp}}{(2\pi)^2}\, e^{ib\cdot p_{\perp}}\, f_{\perp}^{i}(p_{\perp})$$

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and

$$\mathcal{C}(b) = -\frac{g^2 C_2(R) T}{2\pi}\left(K_0(|b|m_D) + \gamma_E + \log(|b|m_D/2)\right)$$

Complete leading order

$$(2\pi)^3 \frac{d\Gamma_{\rm LO}^{\rm odd}}{d^3k} \approx \mathcal{A}(\omega)\Big(C_{\rm Log}^{{\rm odd},(1)}(\omega/T)\log(T/m_f) + C_{2\leftrightarrow 2}^{{\rm odd},(1)}(\omega/T) + C_{\rm LPM}^{{\rm odd},(1)}(\omega/T)\Big)\frac{\mu_A}{T} + \mathcal{O}(\mu_A^3)$$

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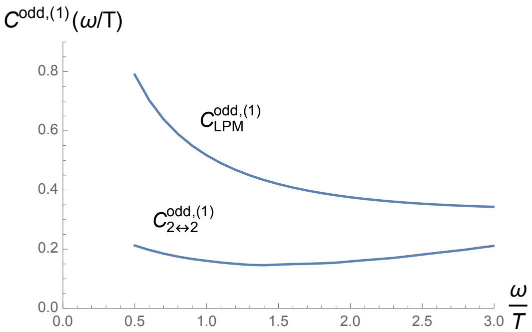

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- AdS/CFT or gauge-gravity duality

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- AdS/CFT or gauge-gravity duality

$$Z_{\text{gauge}}(\text{J}; N_c \gg 1, \lambda \to \infty) \equiv Z_{\text{gravity}}(\phi^{cl}; G_5 \ll 1, \frac{\alpha'}{R^2} \to 0)$$

$$\phi_{cl}(\omega, \mathbf{k}, r) = F(\omega, \mathbf{k}, r)\phi_0(\omega, \mathbf{k})$$

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$$G_R(\omega, \mathbf{k}) = \frac{\delta^2 Z_{\text{gauge}}}{\delta J \delta J} = \frac{\delta^2 S_{\text{on-shell}}}{\delta\phi_0 \delta\phi_0}$$

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- Sakai-Sugimoto model

$$S_{\text{gravity}}(A_M^{cl}; G_5, \frac{\alpha'}{R^2}) \propto \int dx^4 dr\, r^{\frac{1}{4}} \sqrt{\det\left(g_{MN} + 2\pi\alpha' F_{MN}^{cl}\right)} + S_{CS}$$

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where

$$S_{CS} \propto \int dx^4 dr\, \epsilon^{MNPQR} \bar{A}_M F_{NP}^{cl} F_{QR}^{cl} \supset \int d^4x dr\, \bar{A}_0 (\partial_r A_1^{cl})(\partial_3 A_2^{cl})$$

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$$A_{\pm\gamma} \equiv \frac{\frac{d\Gamma}{d^3\vec{k}}(\epsilon_+) - \frac{d\Gamma}{d^3\vec{k}}(\epsilon_-)}{\frac{d\Gamma}{d^3\vec{k}}(\epsilon_+) + \frac{d\Gamma}{d^3\vec{k}}(\epsilon_-)} = \frac{\mathrm{Im}\,\sigma_\chi(k^0)}{\mathrm{Re}\,\sigma_{11}(k^0)}$$

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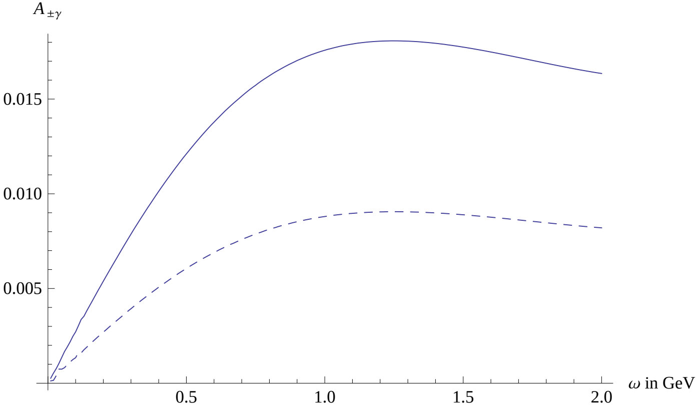

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Conclusion

- the "circular polarization asymmetry" $A_{\pm\gamma}$ probes the imaginary part of the chiral magnetic conductivity $\sigma_\chi(\omega, \mathbf{k})$
- at strong coupling, using AdS/CFT, we found $A_{\pm\gamma} = 0.01$ for $\mu_A = 0.1T$ and $k = \omega = 2T$
- at weak coupling, using pQCD with $\alpha_s = 0.2$, $\mu_A = 0.1T$ and $k = \omega = 2T$, we found $A_{\pm\gamma} \approx 0.03$

Thank You!