DNP 2021

ASU Arizona State University

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Fall DNP Meeting
Oct. 13, 2021
Online

Electromagnetic probes of strongly magnetized quark-gluon plasma

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[X. Wang, I. Shovkovy, L. Yu, and M. Huang, Phys. Rev. D 102, 076010 (2020), arXiv:2006.16254]

[X. Wang and I. Shovkovy, Phys. Rev. D 104, 056017 (2021), arXiv:2103.01967]

[X. Wang and I. Shovkovy, Eur. Phys. J. C 81 (2021), to appear, arXiv:2106.09029]

[X. Wang and I. Shovkovy, work in preparation]

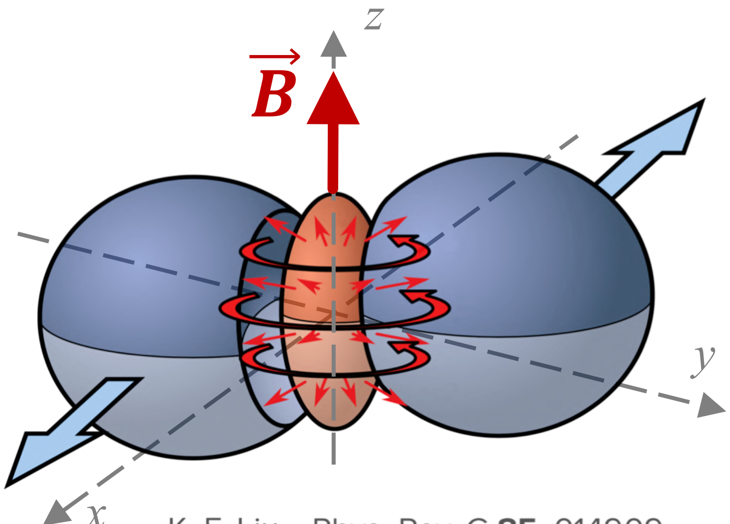
VIRTUAL MEETING

October 11-14, 2021

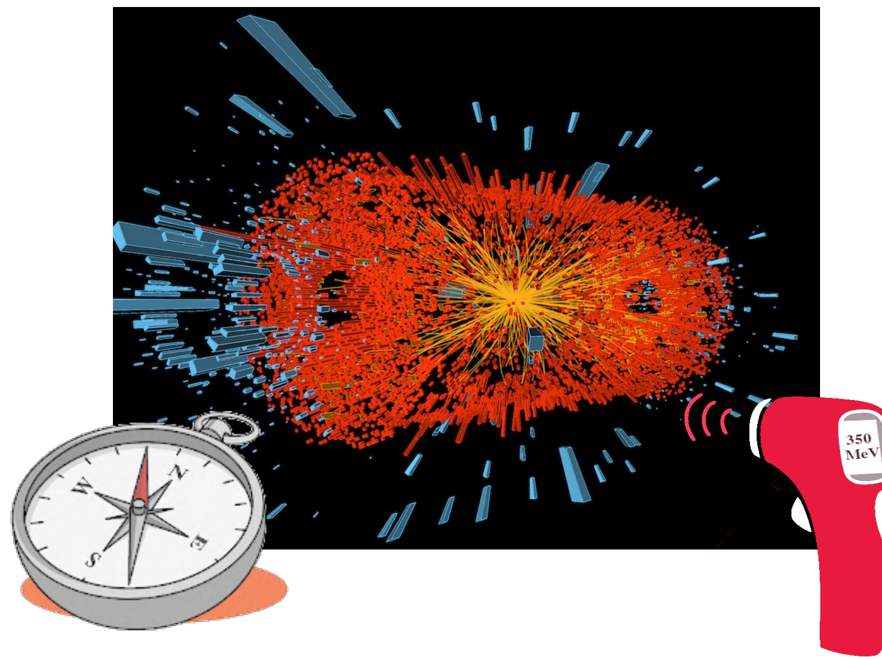
Magnetic field in HICs

- QGP produced at RHIC/LHC is **hot** and **magnetized**

$$T \sim \mathbf{350\ MeV} \quad \text{and} \quad B \sim \boldsymbol{m_\pi^2} \sim \mathbf{10^{18}\ G} \text{ to } \mathbf{10^{19}\ G}$$



K. F. Liu, Phys. Rev. C **85**, 014909



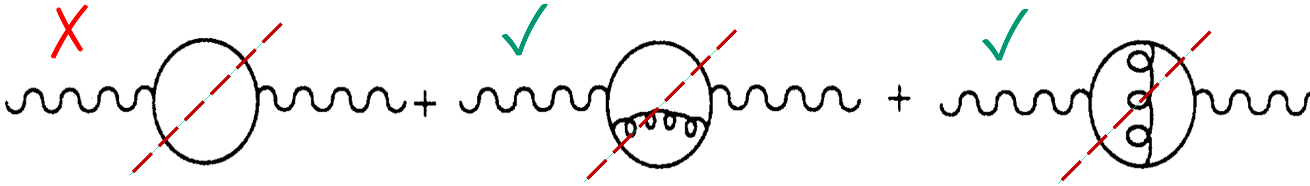
General proposal:

- Electromagnetic probes serve not only as a **thermometer** but also as a **magnetometer** of QGP

Photon emission at $B = 0$

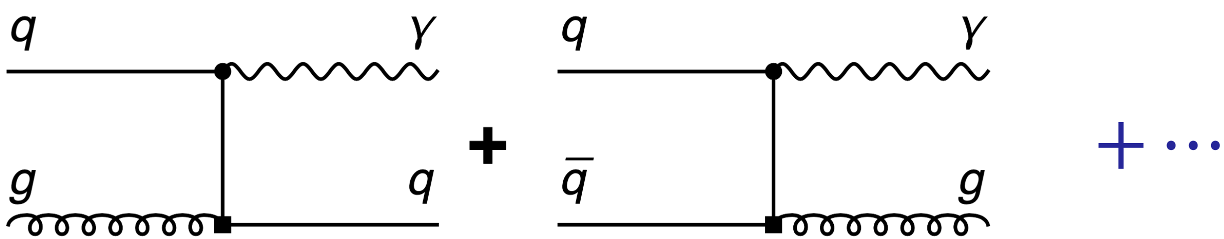
- Compare with the rate of thermal photon emission at B=0

$$\mathrm{Im}[\Pi^{\mu}_{R,\mu}(\Omega, \mathbf{k})] =$$



[Kapusta, Lichard, Seibert, Phys. Rev. D 44, 2774 (1991)]
[Baier, Nakkagawa, Niegawa, Redlich, Z. Physik C 53 (1992) 433]
[Arnold, Moore,Yaffe, JHEP 12 (2001) 009; hep-ph/0111107]
[Ghiglieri et al., JHEP 05 (2013) 010; arXiv:1302.5970]

- Processes ($2 \to 2$):

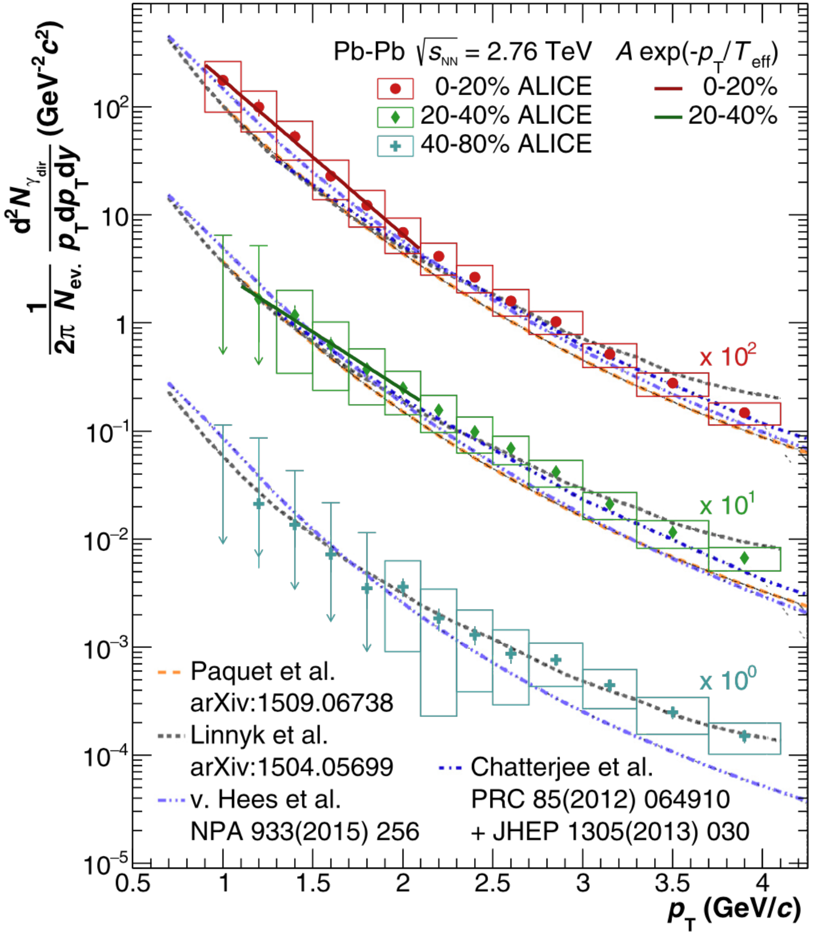


- The approximate result is given by

$$\mathcal{R}_{2\to 2}: \qquad E\frac{dR}{d^3p} = \frac{5}{9}\frac{\alpha\alpha_s}{2\pi^2}T^2 e^{-E/T}\ln\left(\frac{2.912}{g^2}\frac{E}{T}\right)$$

Data for direct photons (ALICE)

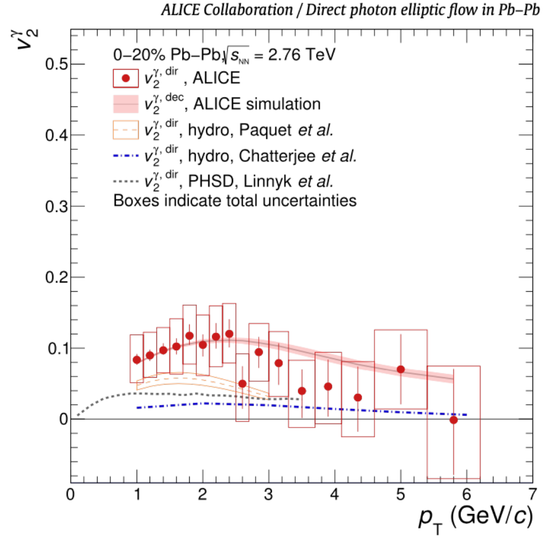
ALICE Collaboration / Physics Letters B 754 (2016) 235–248



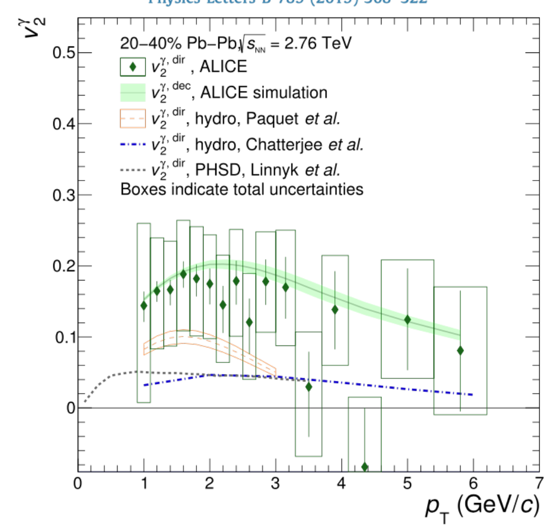
- Thermal radiation consistent with $T_{\text{eff}} = 304$ MeV
- There is a substantial v_2

(larger than models predict)

ALICE Collaboration / Direct photon elliptic flow in Pb–Pb



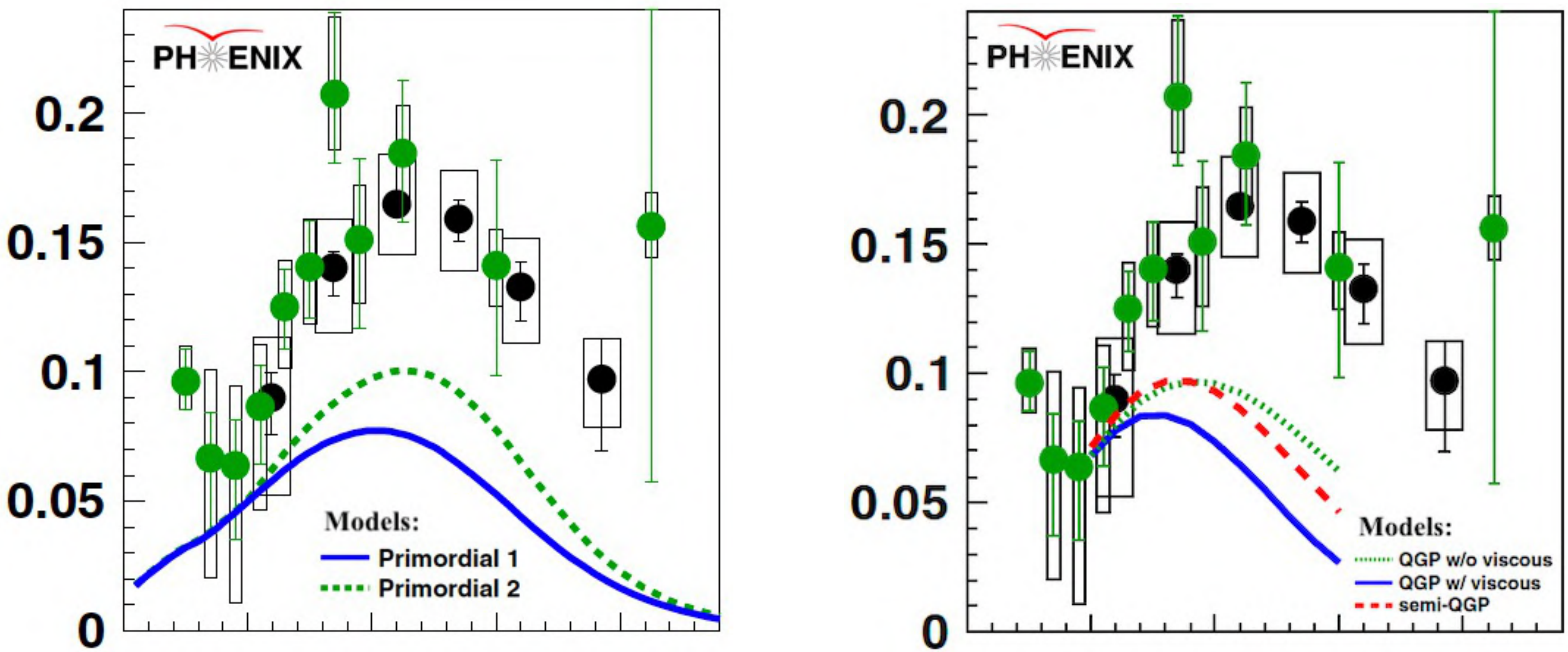
Physics Letters B 789 (2019) 308–322



Data for direct photons (PHENIX)

- Also, a large v_2 for direct photons is observed

(larger than theoretical models predict)



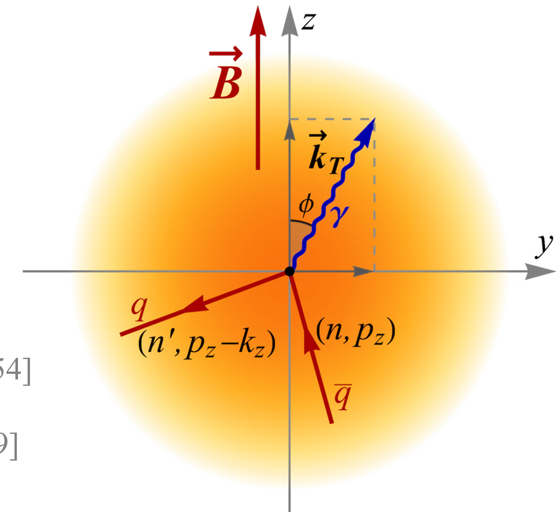
[Adare et al (PHENIX Collaboration), Phys. Rev. C **94**, 064901 (2016)]

Photon emission rates

- The expression for the rate is

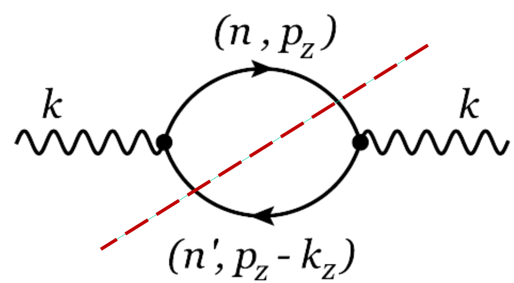
$$\Omega \frac{d^3R}{d^3\mathbf{k}} = -\frac{1}{(2\pi)^3} \frac{\mathrm{Im}[\Pi^{\mu}_{R,\mu}(\Omega, \mathbf{k})]}{\exp(\frac{\Omega}{T}) - 1}$$

[Wang, Shovkovy, Yu, Huang, Phys. Rev. D 102, 076010 (2020), arXiv:2006.16254]
[X. Wang and I. Shovkovy, Phys. Rev. D 104, 056017 (2021), arXiv:2103.01967]
[X. Wang and I. Shovkovy, Eur. Phys. J. C 81 (2021), to appear, arXiv:2106.09029]



- At $\vec{B} \neq 0$, the imaginary part of the polarization tensor

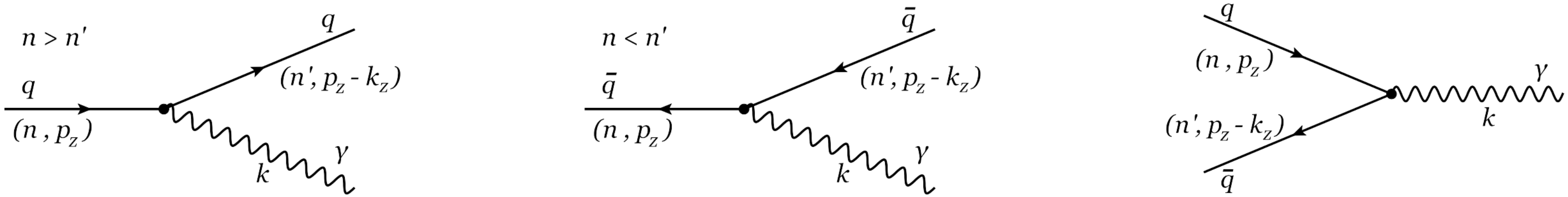
$$\mathrm{Im}[\Pi^{\mu}_{R,\mu}(\Omega, \mathbf{k})] =$$



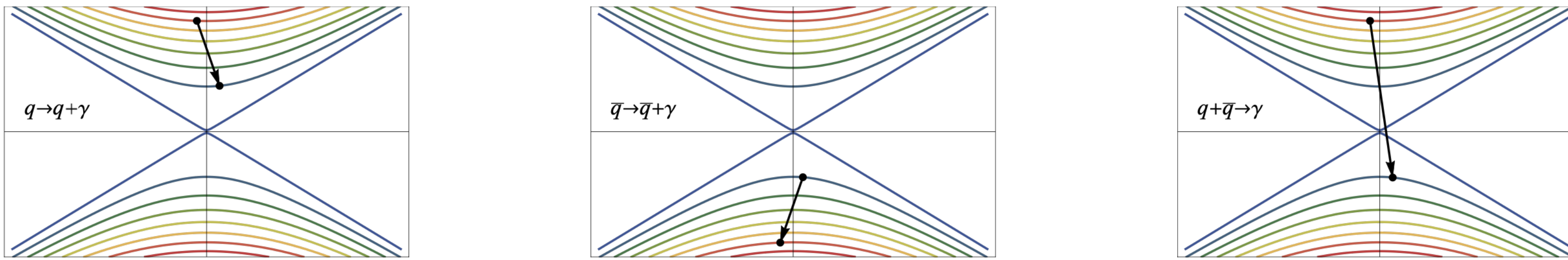
is nonzero at leading order in α_s!

Physics processes

- Relevant physics processes (0^{th} order in α_s):



(a) (b) (c)



The energy momentum conservation

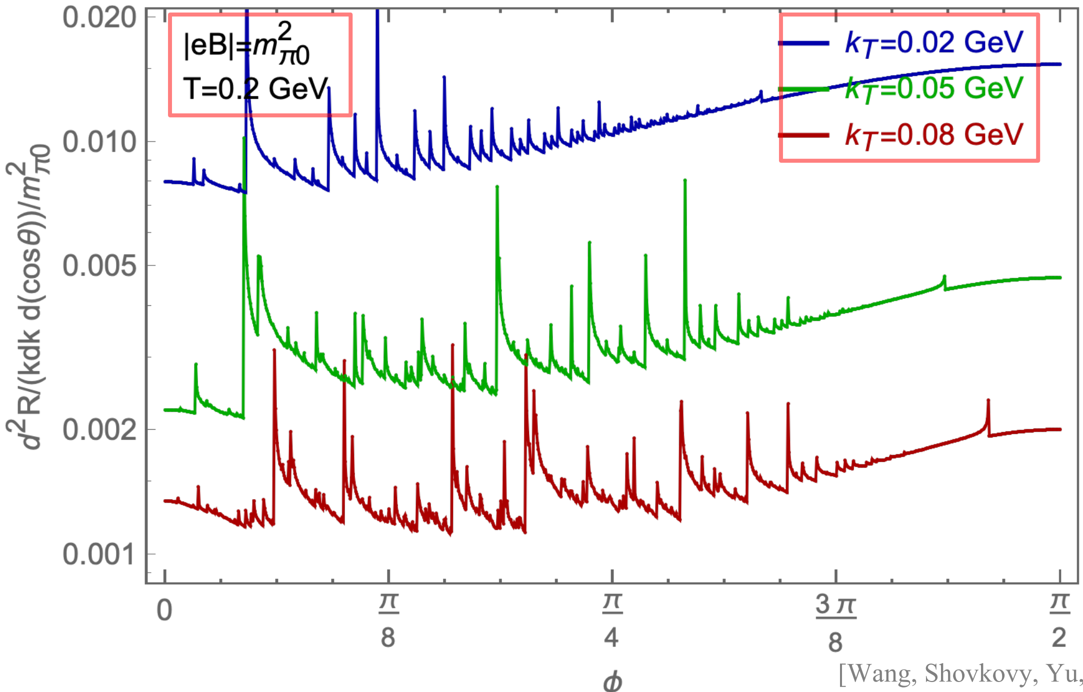
$$E_{n,p_z,f} - \lambda E_{n',p_z-k_z,f} + \eta\Omega = 0$$

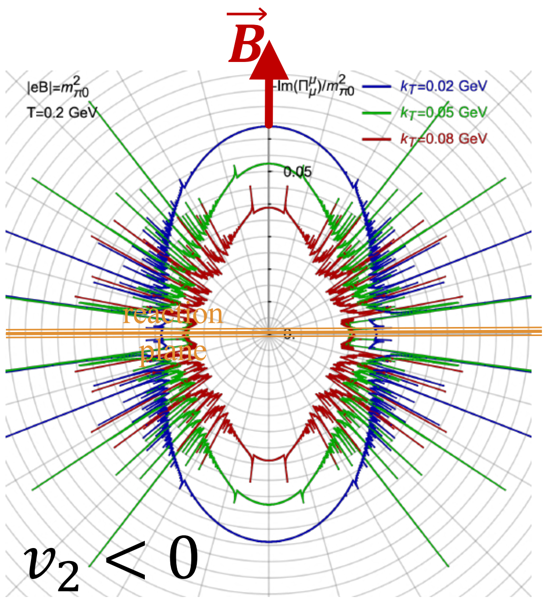
is satisfied for these 1 → 2 and 2 → 1 processes

[Wang, Shovkovy, Yu, Huang, Phys. Rev. D 102, 076010 (2020), arXiv:2006.16254]
$\mu \neq 0$: [X. Wang and I. Shovkovy, Eur. Phys. J. C 81 (2021), to appear, arXiv:2106.09029]

Angular dependence (1)

- At very small k_T, the emission rate is maximal at $\phi = \frac{\pi}{2}$ (i.e., emission **perpendicular** to the reaction plane)
- Effectively, this gives photon "flow" with $v_2 < 0$

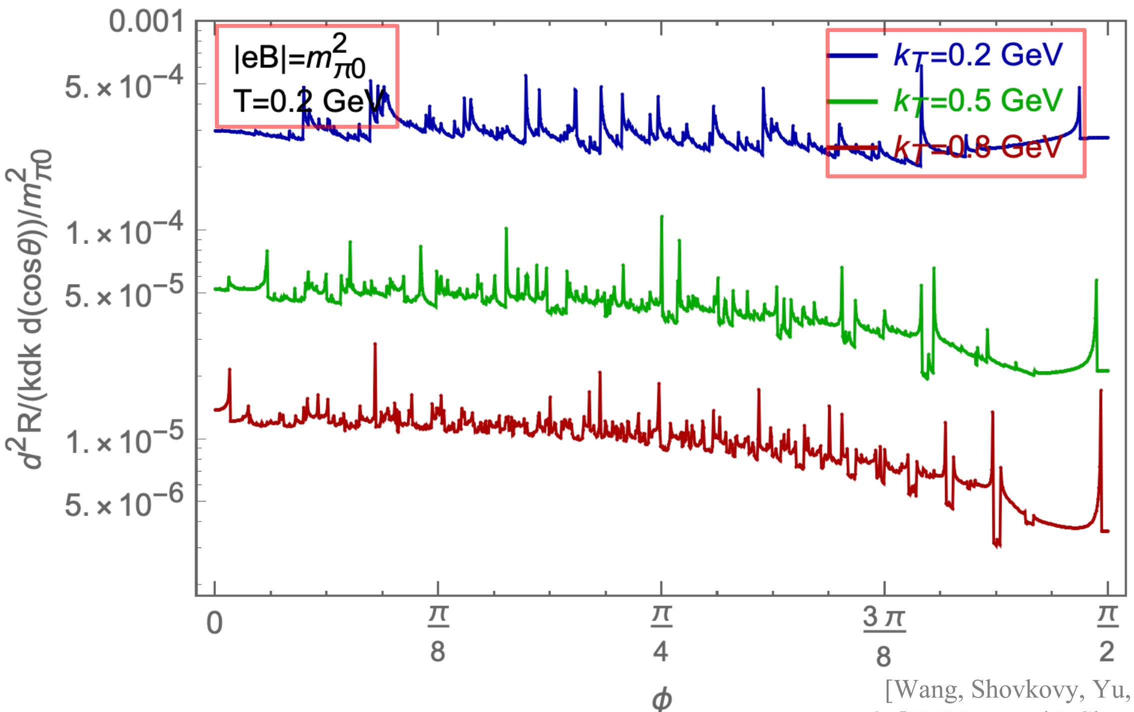


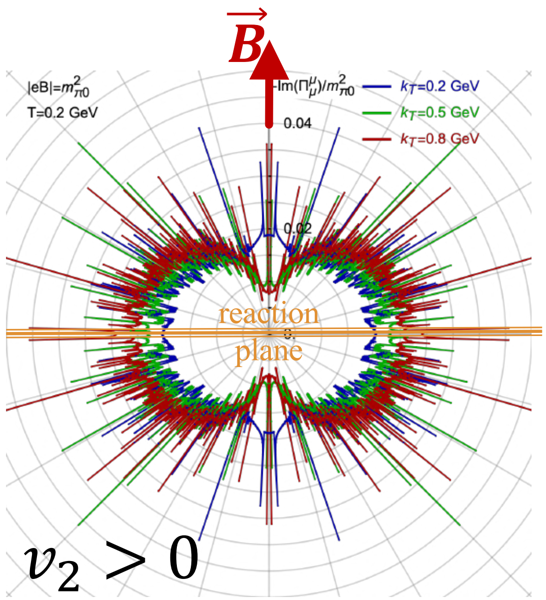


[Wang, Shovkovy, Yu, Huang, Phys. Rev. D 102, 076010 (2020), arXiv:2006.16254]
$\mu \neq 0$: [X. Wang and I. Shovkovy, Eur. Phys. J. C 81 (2021), to appear, arXiv:2106.09029]

Angular dependence (2)

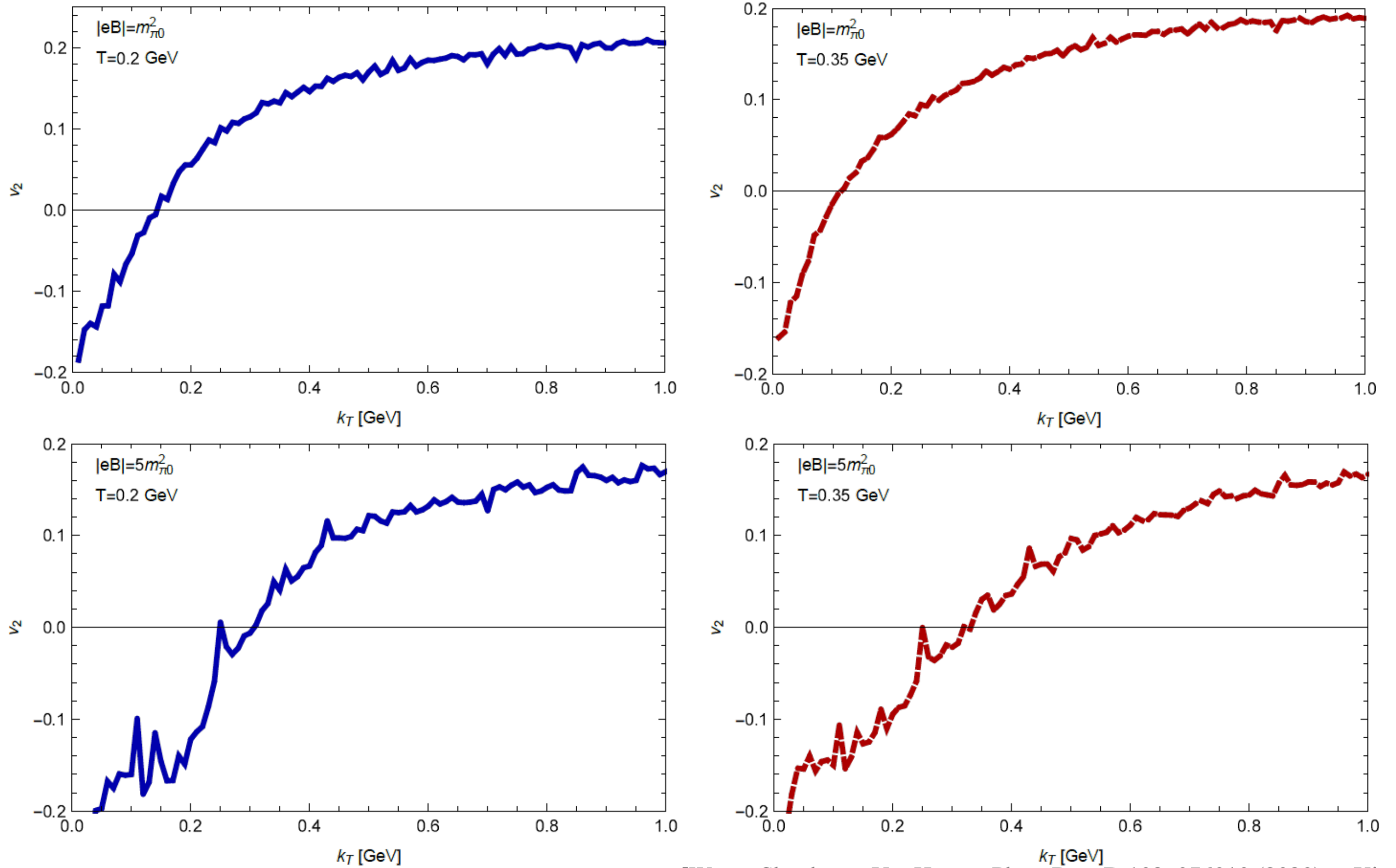
- At large k_T, the emission rate is maximal at $\phi = 0$ (i.e., **parallel** to the reaction plane)
- Effectively, this gives photon "flow" with $v_2 > 0$





[Wang, Shovkovy, Yu, Huang, Phys. Rev. D 102, 076010 (2020), arXiv:2006.16254]
$\mu \neq 0$: [X. Wang and I. Shovkovy, Eur. Phys. J. C 81 (2021), to appear, arXiv:2106.09029]

Nonzero elliptic "flow" (v_2)

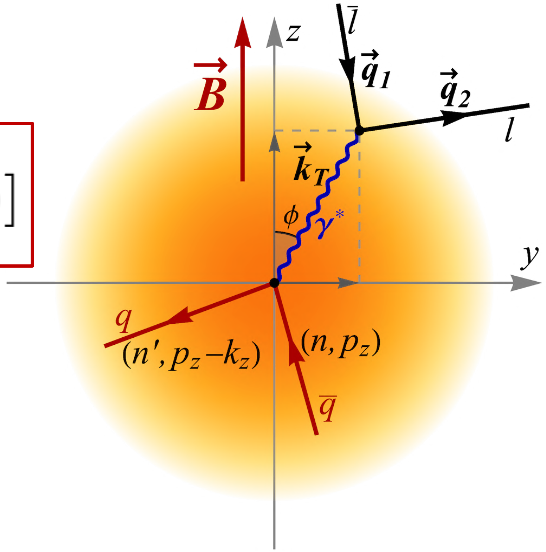


[Wang, Shovkovy, Yu, Huang, Phys. Rev. D 102, 076010 (2020), arXiv:2006.16254]
$\mu \neq 0$: [X. Wang and I. Shovkovy, Eur. Phys. J. C 81 (2021), to appear, arXiv:2106.09029]

Dilepton emission rates

- The expression for the rate is

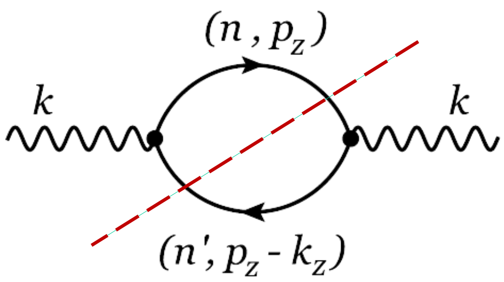
$$\frac{dN}{d^4x d^4k} = -\frac{\alpha}{12\pi^4}\frac{n_B(\Omega)}{k^2}\left(1+\frac{2m_l^2}{k^2}\right)\left(1-\frac{4m_l^2}{k^2}\right)^{1/2}\mathrm{Im}\left[\Pi^{\mu}_{\mu}(\Omega,\mathbf{k})\right]$$



[Wang, Shovkovy, in preparation]

where

$$\mathrm{Im}[\Pi^{\mu}_{R,\mu}(\Omega,\mathbf{k})] =$$

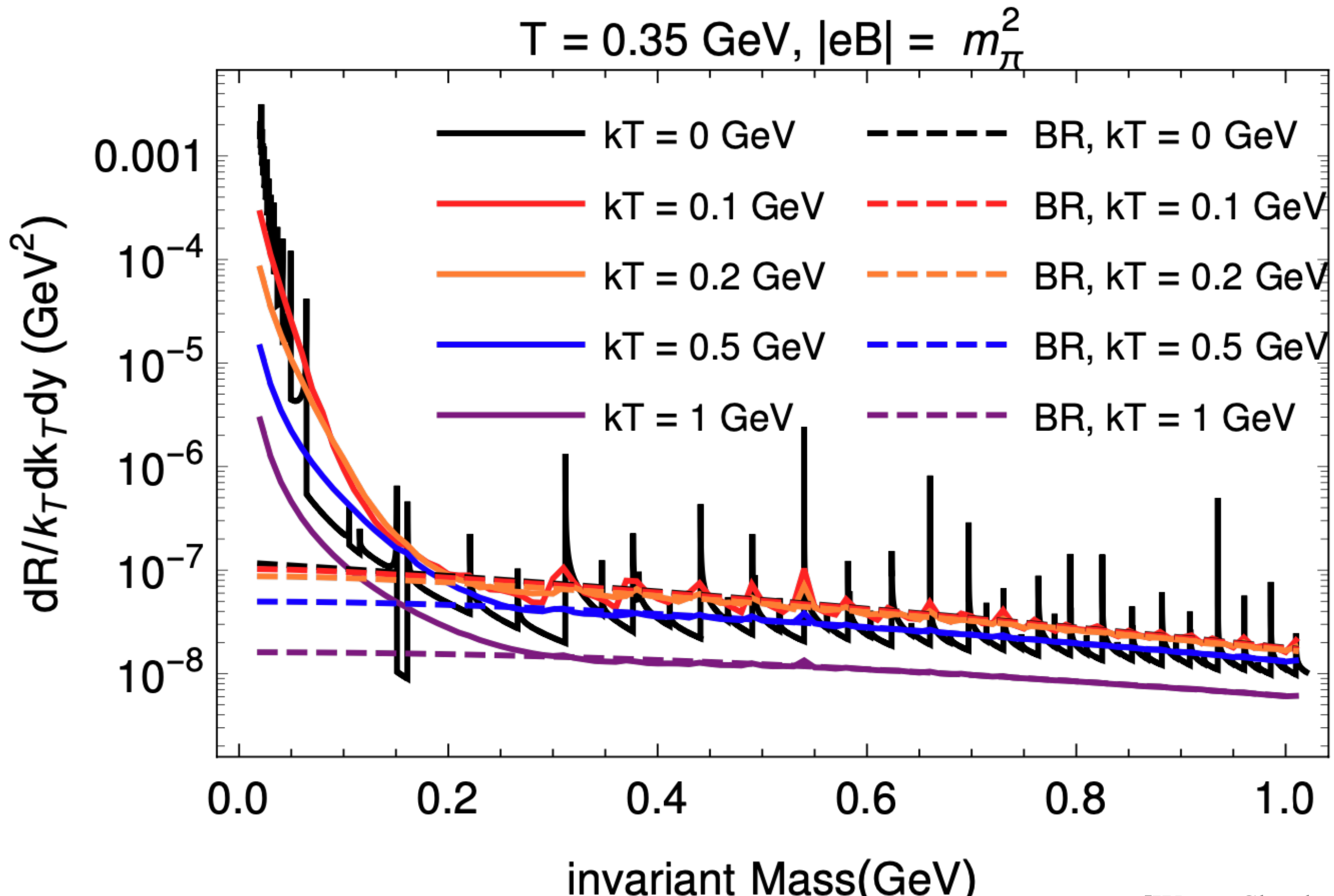


- Compare with the B=0 rate (Born approximation):

$$\frac{dR_{Born}}{d^4x d^4k} = \frac{5\alpha^2 T}{18\pi^4 K} n_B(\Omega) \ln\left(\frac{\cosh\frac{\Omega+K}{4T}}{\cosh\frac{\Omega-K}{4T}}\right)$$

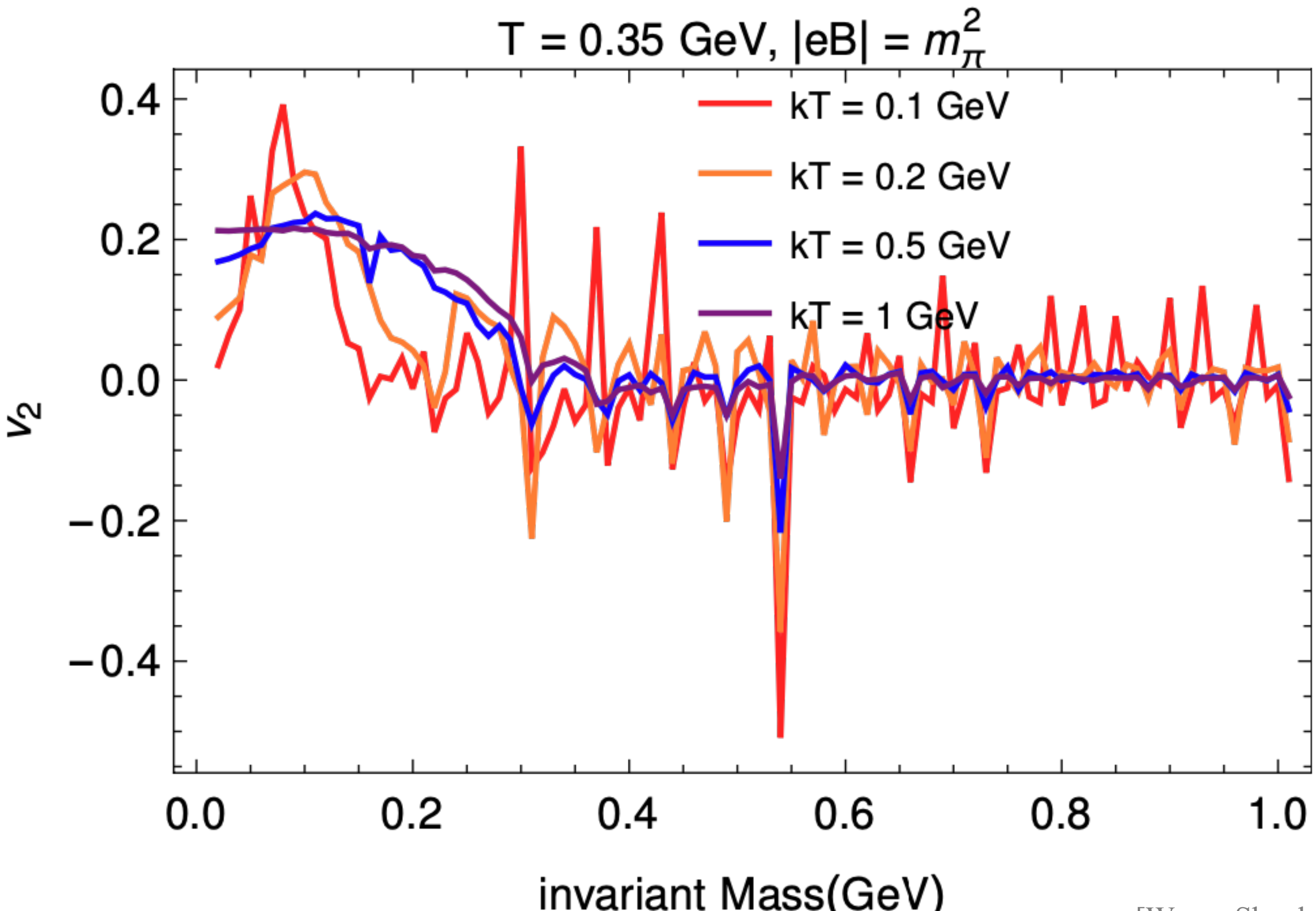
[Cleymans, Fingberg, and Redlich, Phys. Rev. D 35, 2153 (1987)]

Spectrum $(T = 350\text{ MeV}, eB = m_\pi^2)$



[Wang, Shovkovy, in preparation]

v_2 ($T = 350$ MeV, $eB = m_\pi^2$)



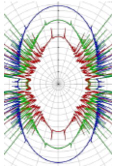
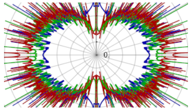
[Wang, Shovkovy, in preparation]

Summary

- $\vec{B} \neq 0$: photons are produced at 0^{th} order in α_s

$$\text{(i)}\;\; q \to q + \gamma, \quad \text{(ii)}\;\; \bar{q} \to \bar{q} + \gamma, \quad \text{(iii)}\;\; q + \bar{q} \to \gamma$$

- Photon emission has pronounced ellipticity

$v_2 < 0$ @ $k_T \lesssim \sqrt{|eB|}$  & $v_2 > 0$ @ $k_T \gtrsim \sqrt{|eB|}$ 

- Dilepton emission is anisotropic, with possible $v_2 > 0$

- A nonzero ellipticity of photon & dilepton (?) emission are indirect "measures" of the magnetic field in collisions