Thermal Photon Puzzles in Low Momentum Region

Yi Yin
BNL/U. Illinois, Chicago

Workshop on Thermal Photons and Di-leptons in Heavy Ion Collisions

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Based on: YY, arXiv:1312.4434(PRC)

Thanks for staying awake!

Thermal Photon Puzzle

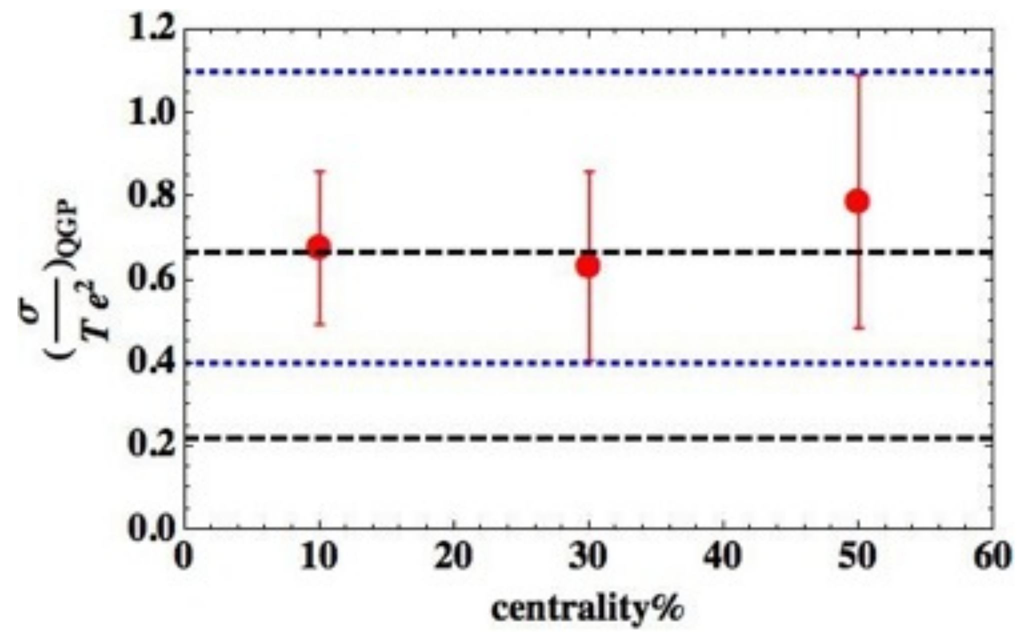
- "Enhanced Photon Production Puzzle": Photon production measured in experiment is larger than the results of hydro. + (HTL)pQCD evolution.(See C.Gale's talk in this morning.)

- "Photon v2 puzzle": Photons spectrum has large v2 (azimuthal anisotropy)

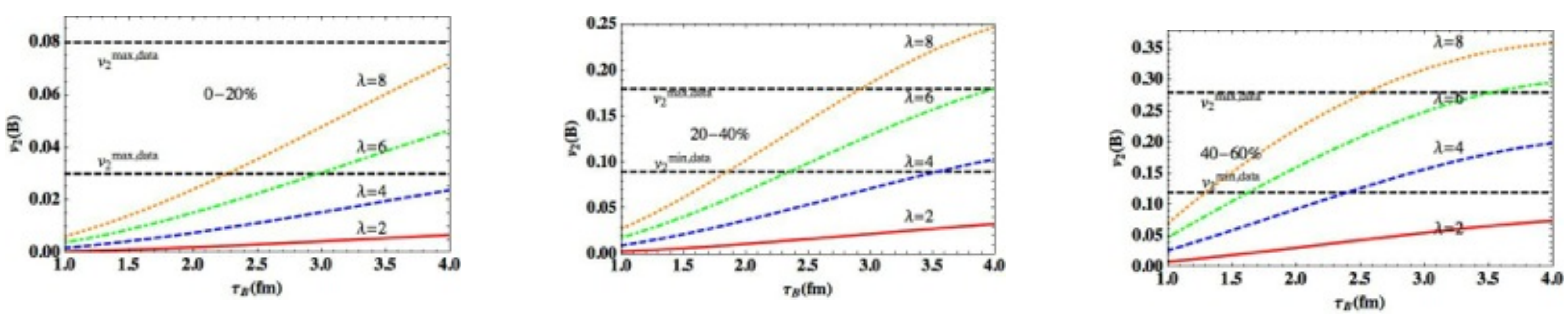
- This talk: thermal photon puzzle in low momentum region. (In this talk, low momentum means $p_\perp < \pi T$)

Outline

- Part I: Conductivity of QGP is extracted based on low momentum photon data.



- Part II: low momentum behavior of photon v2 is remarkable. Possible contribution from magnetic field is analyzed.



Part I: Electrical conductivity of QGP from photon production

Photon production in heavy-ion collisions

- Photon produced per volume per time is related to Green's function of QGP:

$$P_T^{ij} = \delta^{ij} - \hat{p}^i\hat{p}^j$$

$$\omega\frac{d\Gamma_\gamma}{d^3\vec{p}} = -\frac{n_B(\omega/T)}{(2\pi)^3}P_T^{ij}\mathrm{Im}\left[G_{ij}^R(\omega = |\vec{p}|)\right]$$

Retarded correlator: $G_R^{\mu\nu} \sim \langle J^\mu J^\nu \rangle$

- Photons are produced during the full evolution of the fireball with shifted frequency:

$$\frac{dN_\gamma}{p_t dp_t d\phi_p dY} = \int_{T\geq T_f} d^4x\omega_{\mathrm{shift}}\frac{d\Gamma_\gamma}{d^3p'}\Big|_{\omega_{\mathrm{shift}}=|\vec{p}|}$$

$$\omega_{\mathrm{shift}} = p^\mu_{\mathrm{Lab}}u_\mu$$

Photon frequency is shifted in the rest frame of fluid.

- To study photon spectrum, we need i) theoretical understanding of photon rate and ii) hydrodynamic evolution.

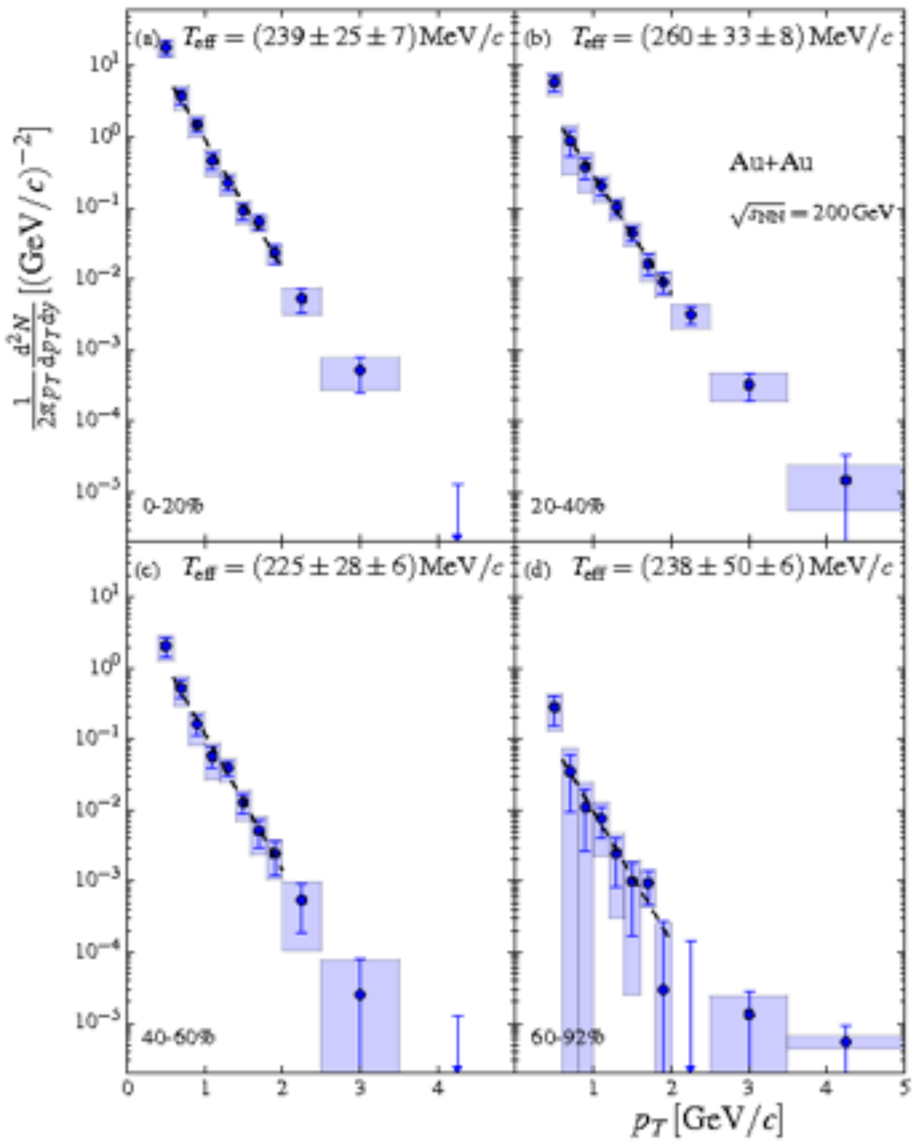
Photon and thermal correlators

- Photon production in heavy-ion collisions has been studied by evolving (HTL)pQCD photon rate with hydrodynamic simulations.
- QGP is strongly coupled! pQCD rate may not be applicable for photon energy below a few GeV!
- Determination of correlation functions from microscopic theory is challenging.
- In low frequency limit, a macroscopic description is possible!

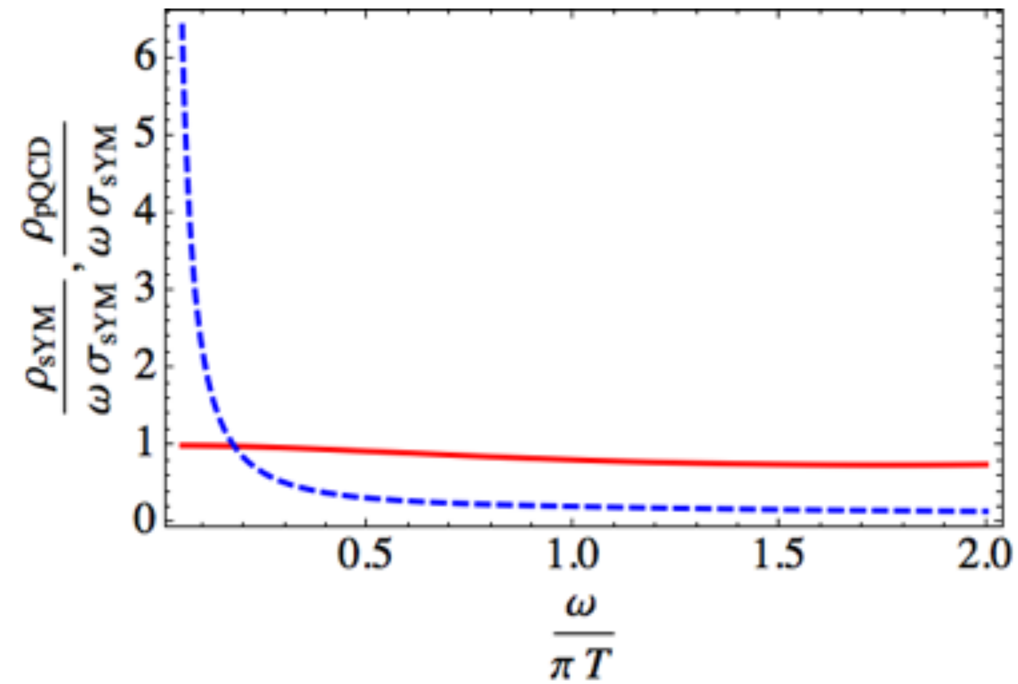
$$P_T^{ij}\,\mathrm{Im}\left[G_{ij}^R(\omega=|\vec{p}|)\right)_{B=0}=\frac{\alpha_{\mathrm{EM}}\omega\sigma_0}{\pi^2 e^2}$$

Soft Photon and conductivity

- The lowest pt in experiment: 0.5 GeV. (PHENIX, 1405.3940)



$\pi T_{QGP} \approx 1GeV$



(SYM vs pQCD, hep-th/0607237)

- Strongly interacting system has a wider hydrodynamic regime!

- We will use the hydrodynamic approximation to study the lowest pt photon data

$$P_T^{ij}\,\mathrm{Im}\left[G^R_{ij}(\omega = |\vec{p}|)\right)_{B=0} = \frac{\alpha_{\rm EM}\omega\sigma_0}{\pi^2 e^2}$$

Electrical conductivity of QGP

- We write down the rate

$$\frac{dN_\gamma}{2\pi p_t dp_t dY} = \frac{\alpha_{\rm EM}}{\pi^2}\int_0^{2\pi}\frac{d\phi_p}{2\pi}\int_{T\geq T_f} d^4x \frac{\omega_{\rm shift}\sigma}{\exp(\omega_{\rm shift}/T)-1} \qquad \omega_{\rm shift} = p^\mu_{\rm Lab}u_\mu$$

- We estimate conductivity at QGP temperature by computing the following ratio.

$$\langle\frac{\sigma}{e^2T}\rangle \equiv \frac{\frac{dN_\gamma}{2\pi p_t dp_t dY}}{\frac{\alpha_{\rm EM}}{\pi^2}\int_0^{2\pi}\frac{d\phi_p}{2\pi}\int_{T\geq T_f} d^4x \frac{\omega_{\rm shift}T}{\exp(\omega_{\rm shift}/T)-1}}$$

From the data

(NB: σ/T is dimensionless, similar to η/s .)

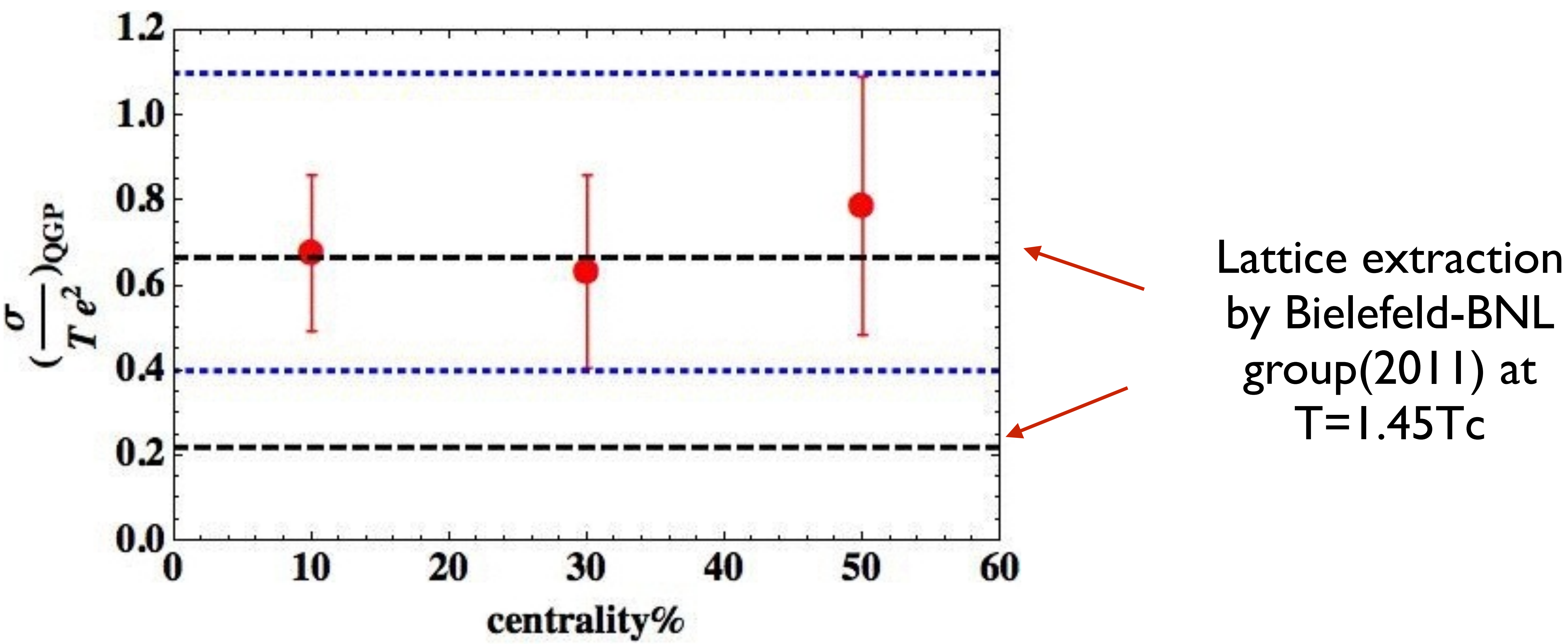
- We evolve the integral with realistic hydrodynamic background.

(The realistic hydrodynamic background is from Heinz' group, available online: https://wiki.bnl.gov/TECHQM/index.php/Main_Page)

Electrical conductivity of QGP

- PHENIX data, different for different centralities.
- Hydrodynamic background, different for different centralities.
- The ratio has a weak-dependence on centralities! Conductivity is the properties of QGP!

YY, ArXiv:1312.4434(PRC)



Part II: Photon v_2 puzzle in low momentum region

Potential sources to photon v_2

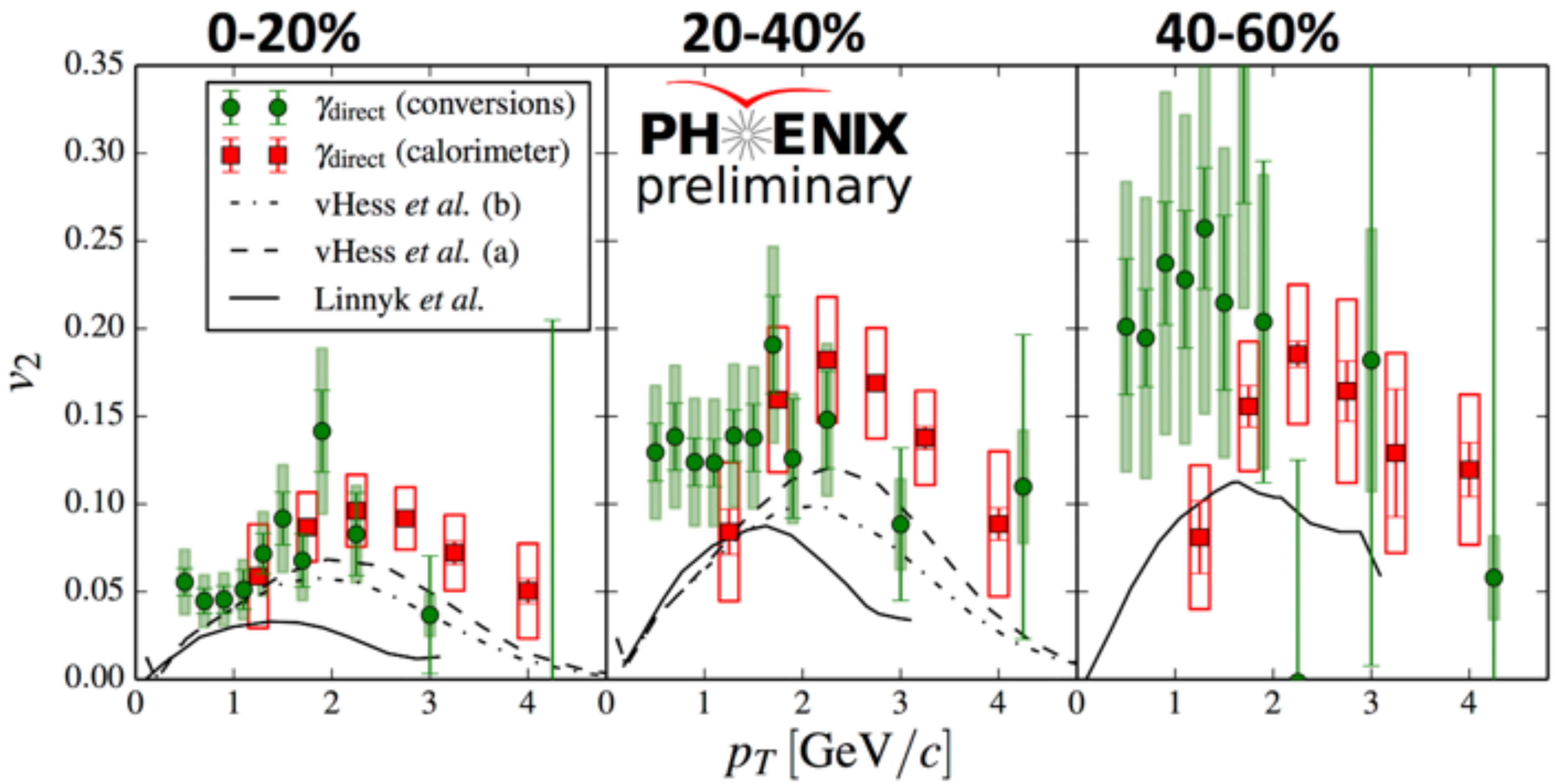
$$\frac{dN_\gamma}{p_t dp_t d\phi_p dY} = \int_{T \geq T_f} d^4x \omega_{\rm shift} \frac{d\Gamma_\gamma}{d^3p'}\Big|_{\omega_{\rm shift}=|\vec{p}|} \qquad \omega_{\rm shift} = p^\mu_{\rm Lab} u_\mu$$

- Two possible sources to photon anisotropy.
  - anisotropy due to flow
  - anisotropy due to production rate
- Can one distinguish contribution from those two sources?
  - In low momentum region, assuming conductivity tensor is isotropic:

$$G_R^{ij}(\omega) = -i\omega\sigma_{ij} = -i\omega\sigma_0\delta_{ij} \qquad \omega\frac{d^3\Gamma}{dp^3} = \frac{P_T^{ij} Im\left[G_{ij}(\omega)\right]}{e^{\omega/T}-1} \sim \sigma_0 T$$

- Flow effects is highly suppressed in low momentum region!

Soft Photon v_2 Puzzle



- Photon v_2 tends to approach a positive value in low momentum limit!
- This fact is very hard to be explained by the flow!

Effects of Magnetic Field

- Conductivity tensor is anisotropic in the presence of background magnetic field. $$\sigma^{ij} = \sigma_0 \delta^{ij} - \Delta\sigma_{B,T}\left(\delta^{ij} - \hat{B}^i \hat{B}^j\right) + \Delta\sigma_{B,L}\hat{B}^i \hat{B}^j$$

- Under Drude approximation

$$r_T = \frac{\Delta\sigma_{T,B}}{\sigma_0} = \frac{(\omega_B \tau_{\rm rel})^2}{1 + (\omega_B \tau_{\rm rel})^2} \qquad \omega_B = \frac{q_f B}{M} \qquad \Delta\sigma_L = 0$$

- The contribution from magnetic field to photon azimuthal in low momentum region can be estimated as $v_2(B) \approx \langle \frac{r_T}{8(1 - \frac{3}{4} r_T)} \rangle_{\rm average}$

- To estimate $\omega_B \tau_{\rm rel}$, we recall results as extrapolated from SYM theory:

$$(\omega_B \tau_{\rm rel})_{\rm SYM} = (\frac{q_f B \,\tau_{\rm rel}}{M})_{\rm SYM} \approx \frac{q_f B}{2.1\pi T^2} \qquad (\frac{M}{\tau_{rel}})_{\rm SYM} = \frac{\pi\sqrt{g_s^2 N_c}}{2} T^2$$

- We also introduce a dimensionless parameter:

$$(\omega_B \tau_{\rm rel})_{\rm QGP} = \lambda (\omega_B \tau_{\rm rel})_{\rm SYM}$$

Estimating effects from magnetic field

- We have estimated the contribution from magnetic field to photon anisotropy using realistic hydrodynamic background for pt=0.5GeV .

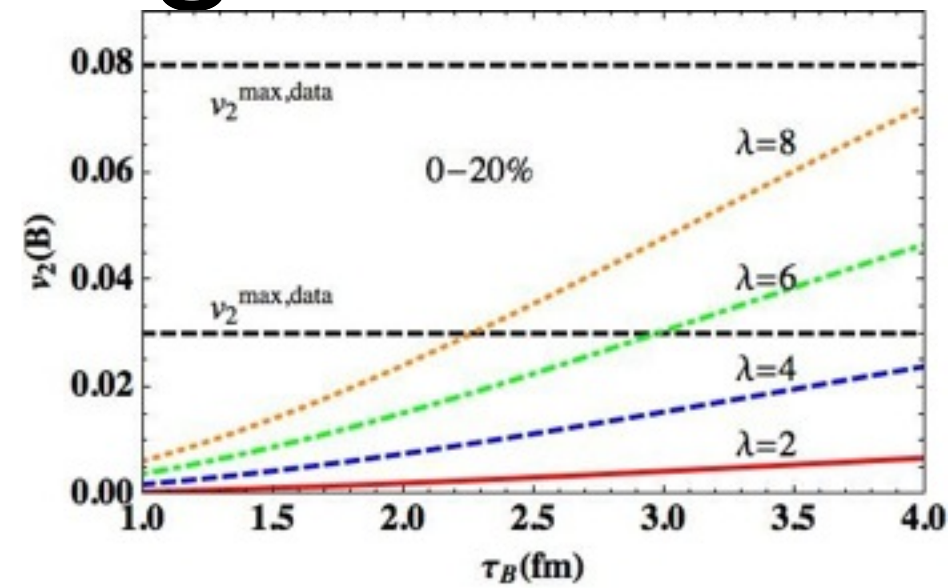
$$(\omega_B \tau_{\mathrm{rel}})_{\mathrm{QGP}} = \lambda(\omega_B \tau_{\mathrm{rel}})_{\mathrm{SYM}}$$

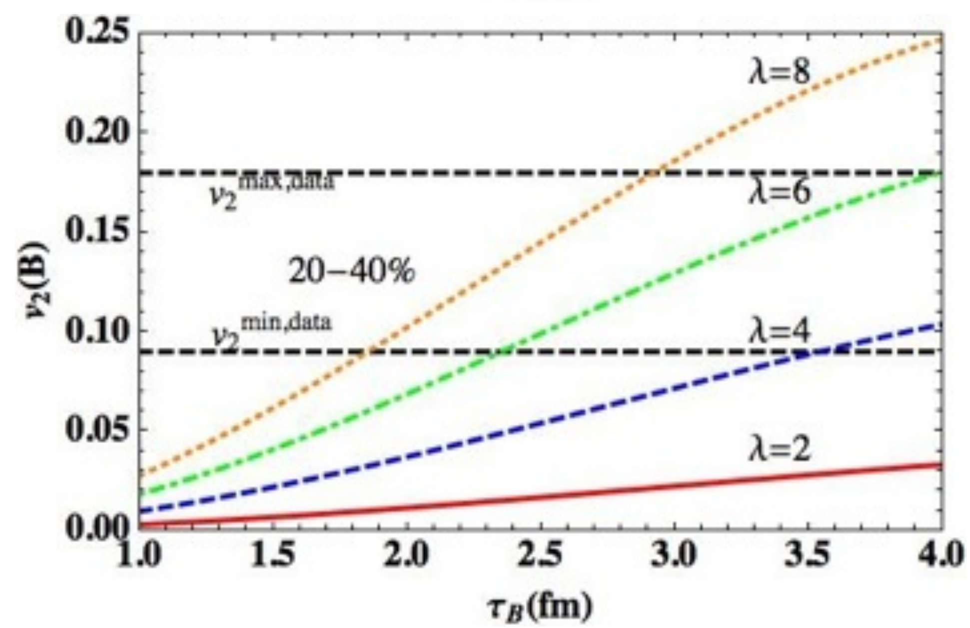
Taking Bjorken time dependent and homogeneous B.

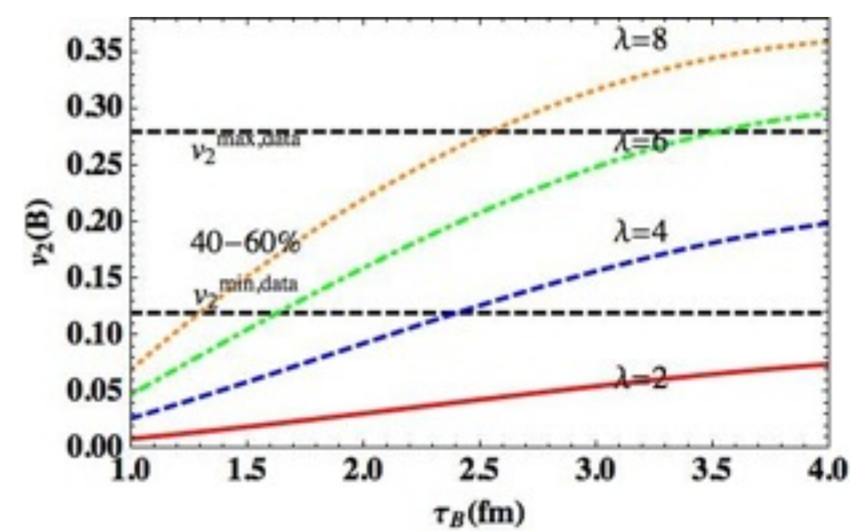
$$eB(\tau) = (eB)_{max}/(1+(\tau/\tau_B)^2)$$

Magnetic field and anomaly will give a sizable contribution to photon anisotropy only if:

$$\tau_B \sim 2-3\mathrm{fm} \qquad (\omega_B \tau) \sim 4-6(\omega_B\tau)_{\mathrm{SYM}}$$







Concluding Remark

- Electrical conductivity of QGP is extracted from photon data. The results is in line with lattice data.

- "Enhanced photon production puzzle": might be related to uncertainties in photon emission rate.

- "Photon v_2 puzzle" in low momentum region: intriguing! Can not be explained by magnetic field if the life time of magnetic field is short.