Photon production by gluon fusion and splitting in the presence of magnetic fields of arbitrary strength

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arXiv: 2406.18673 [hep-ph]

- Alejandro Ayala
- Jorge Jaber
- Jorge Medina

PHYSICAL REVIEW D **110,** 076021 (2024)

Two-gluon one-photon vertex in a magnetic field and its explicit one-loop approximation in the intermediate field strength regime

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We find the general structure for the two-gluon one-photon vertex in the presence of a constant magnetic field. We show that, when accounting for the symmetries satisfied by the strong and electromagnetic interactions under parity, charge conjugation and gluon interchange, and for gluons and photons on mass-shell, there exist only three possible tensor structures that span the vertex. These correspond to external products of the polarization vectors for each of the particles in the vertex. We also explicitly compute the one-loop approximation to this vertex in the intermediate field strength regime, which is the most appropriate one to describe possible effects of the presence of a magnetic field to enhance photon emission during preequilibrium in peripheral relativistic heavy-ion collisions. We show that the most favored direction for the photon to propagate is in the plane transverse to the field, which is consistent with a positive contribution to v_2 and may help to understand the larger than expected elliptic flow coefficient measured in this kind of reaction.

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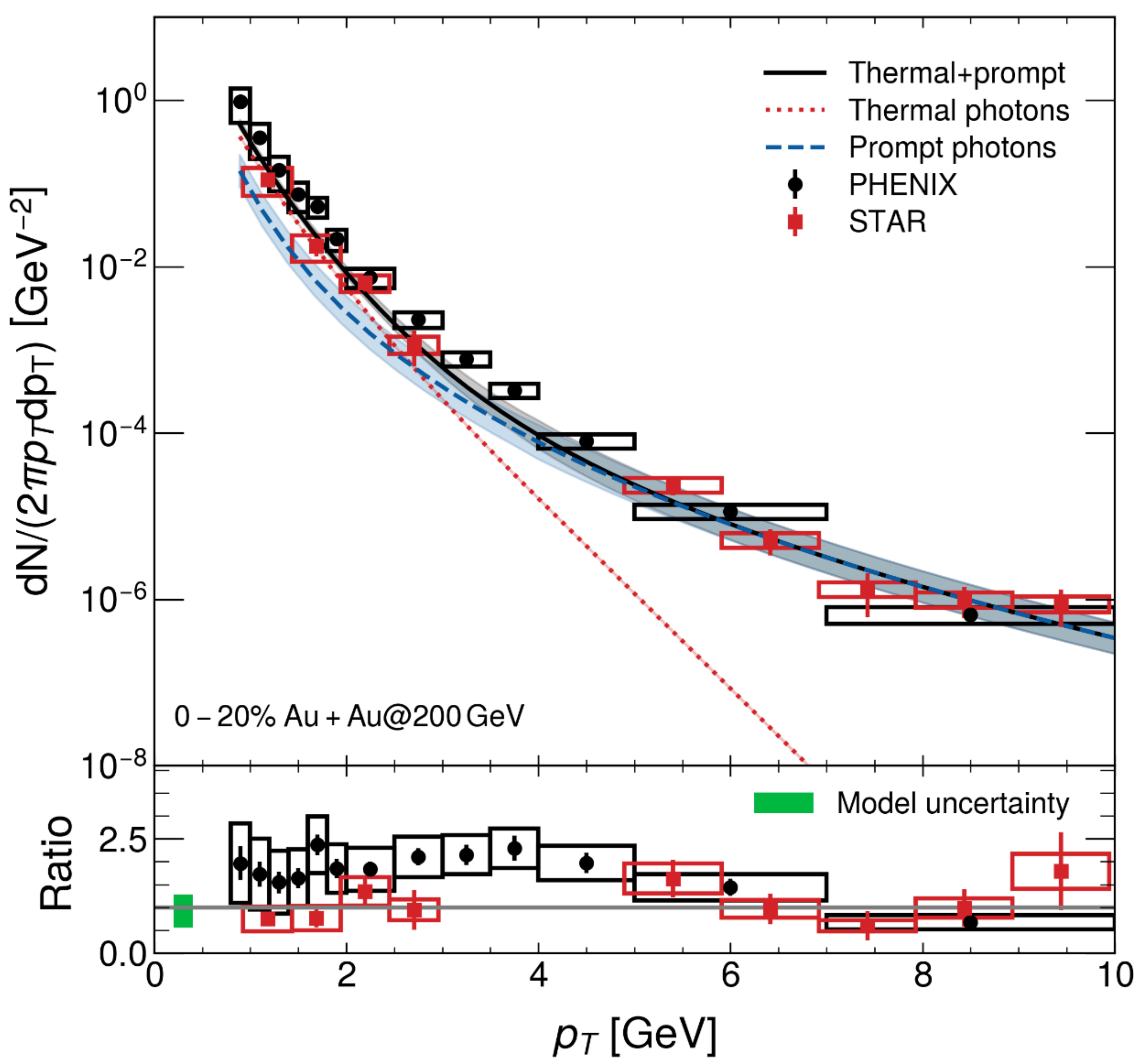
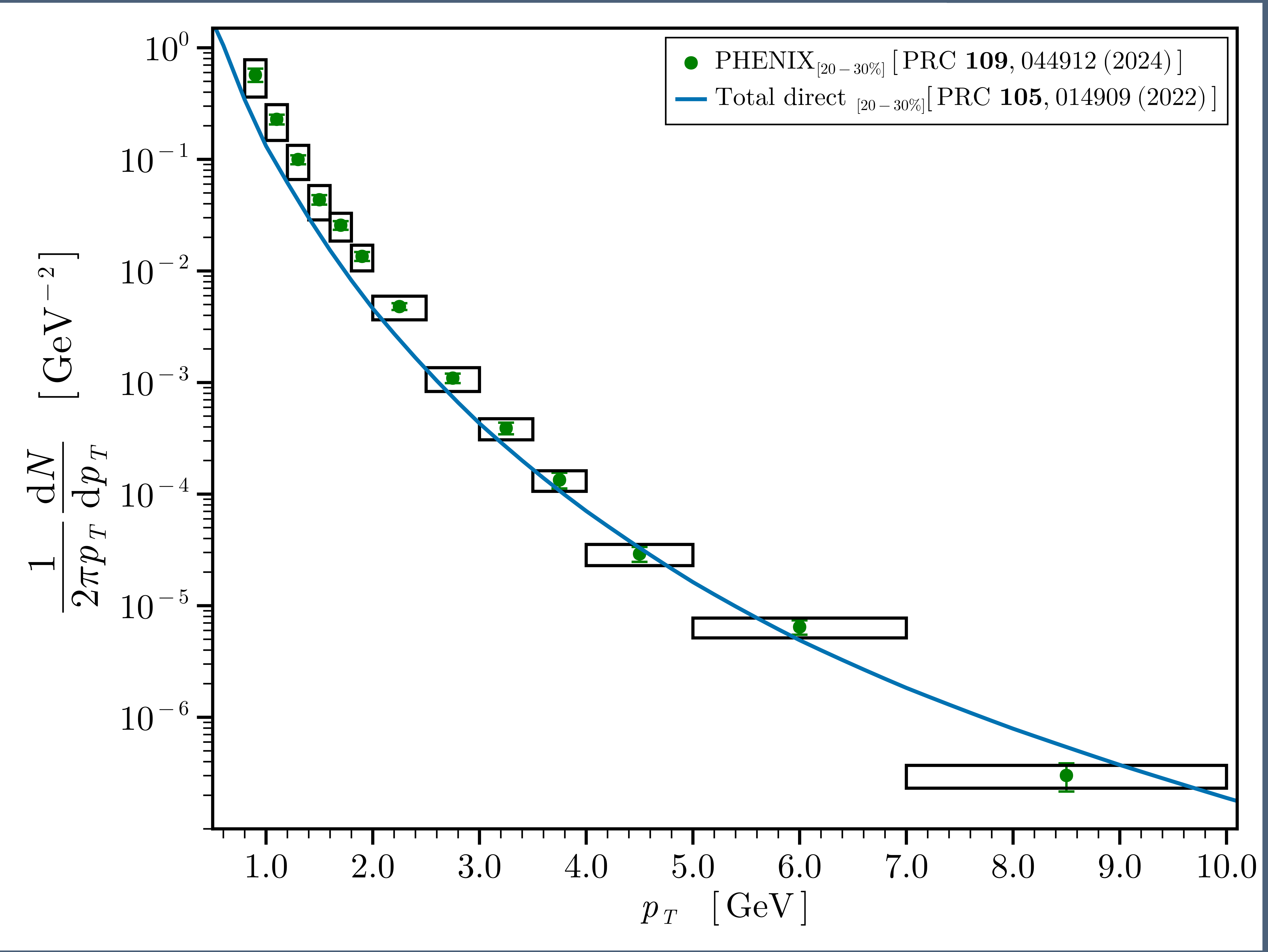
Outline of this talk

- Direct photon puzzle
- Motivation for photon production processes induced by magnetic fields
- The two-gluon one-photon vertex in the presence of a magnetic field
- Preliminary results for excess photon yield
- Conclusions

Direct photon puzzle

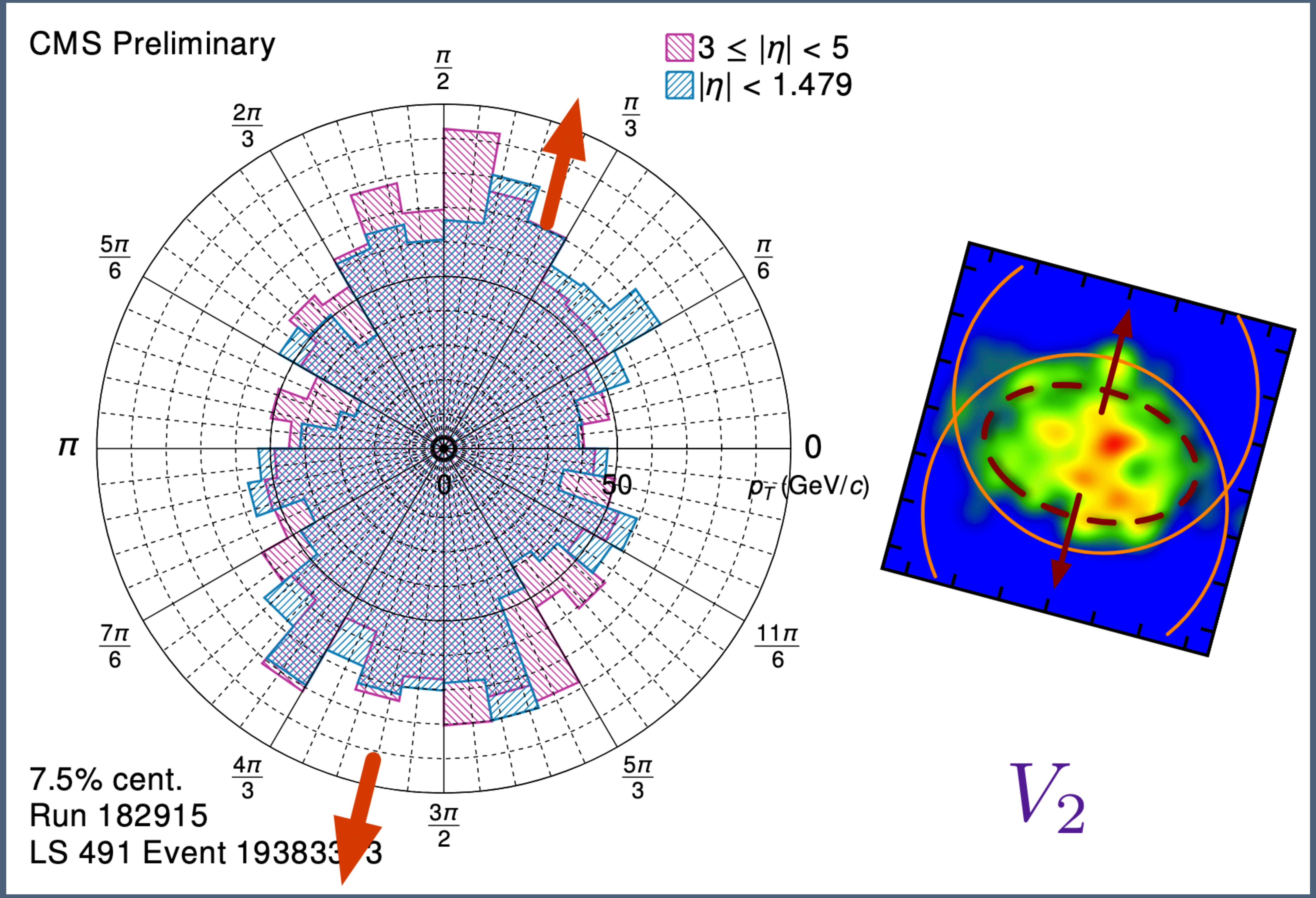


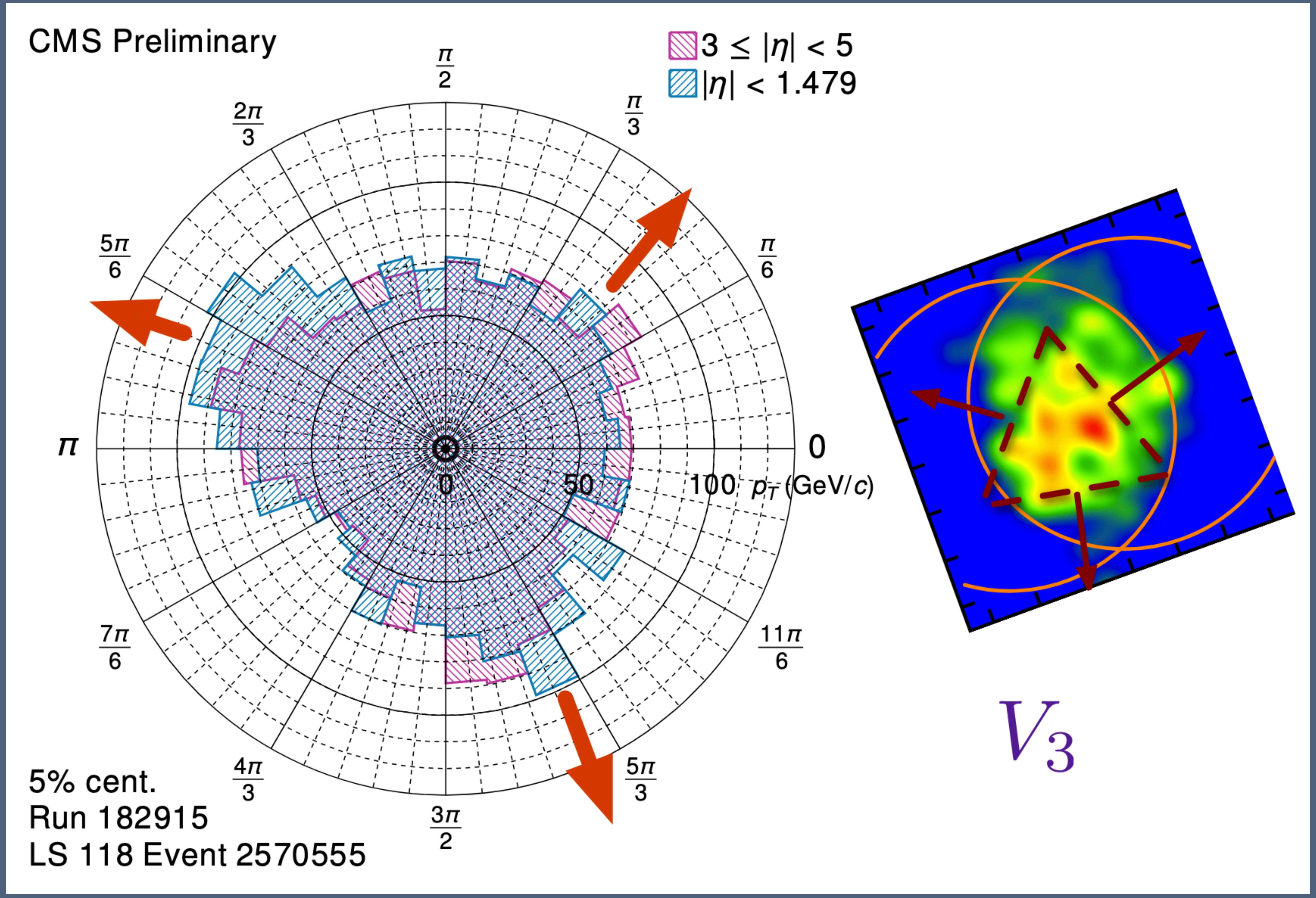
arXiv:2511.08773
State-of-the-art computations, old data



See G. David's talk

Elliptic and triangular flow



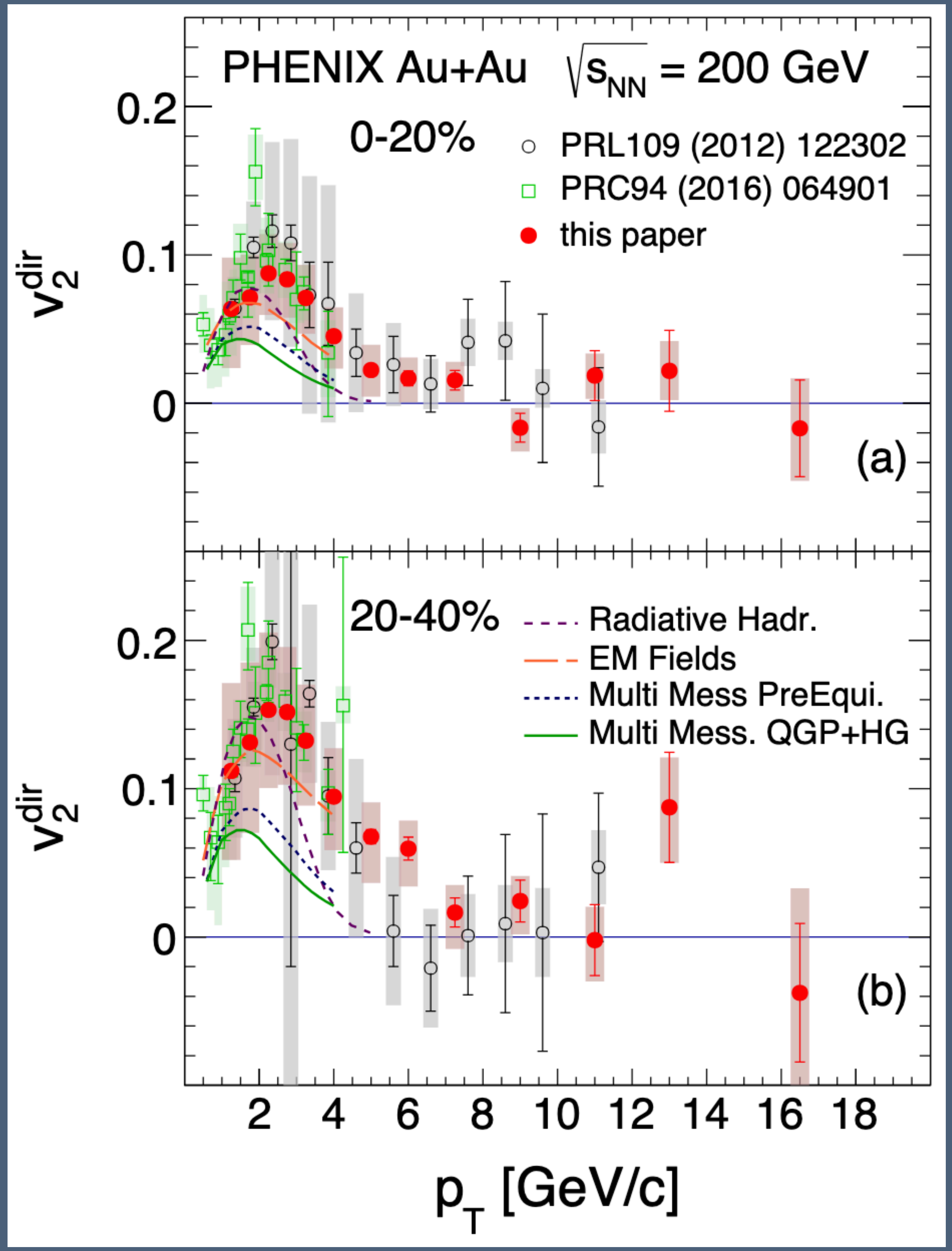


D. Teaney, ASU Colloqium

https://www.public.asu.edu/~ishovkov/colloquium/slides/Colloquium_Slides_Teaney.pdf

Photon elliptic and triangular flow

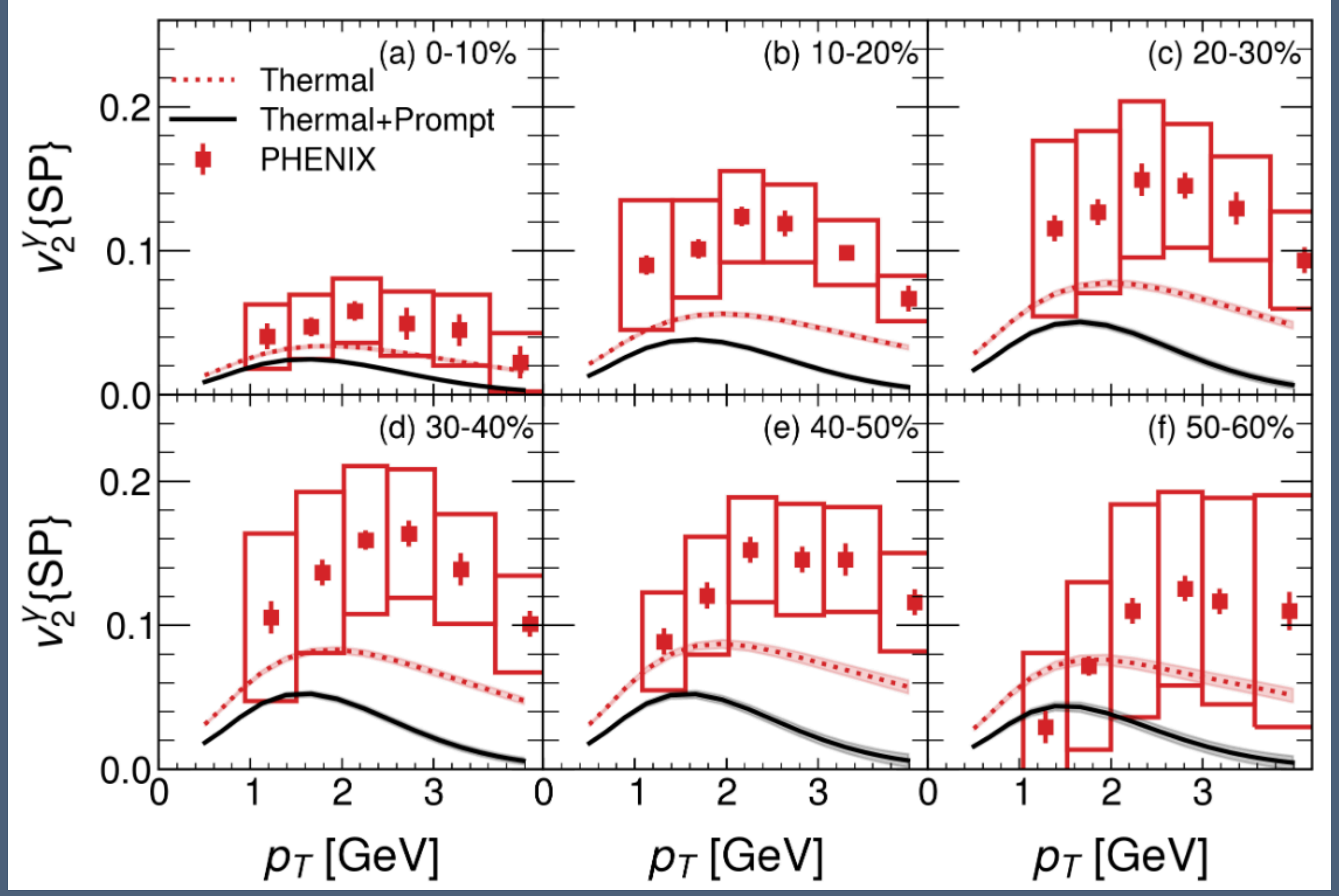
State-of-the-art experimental data

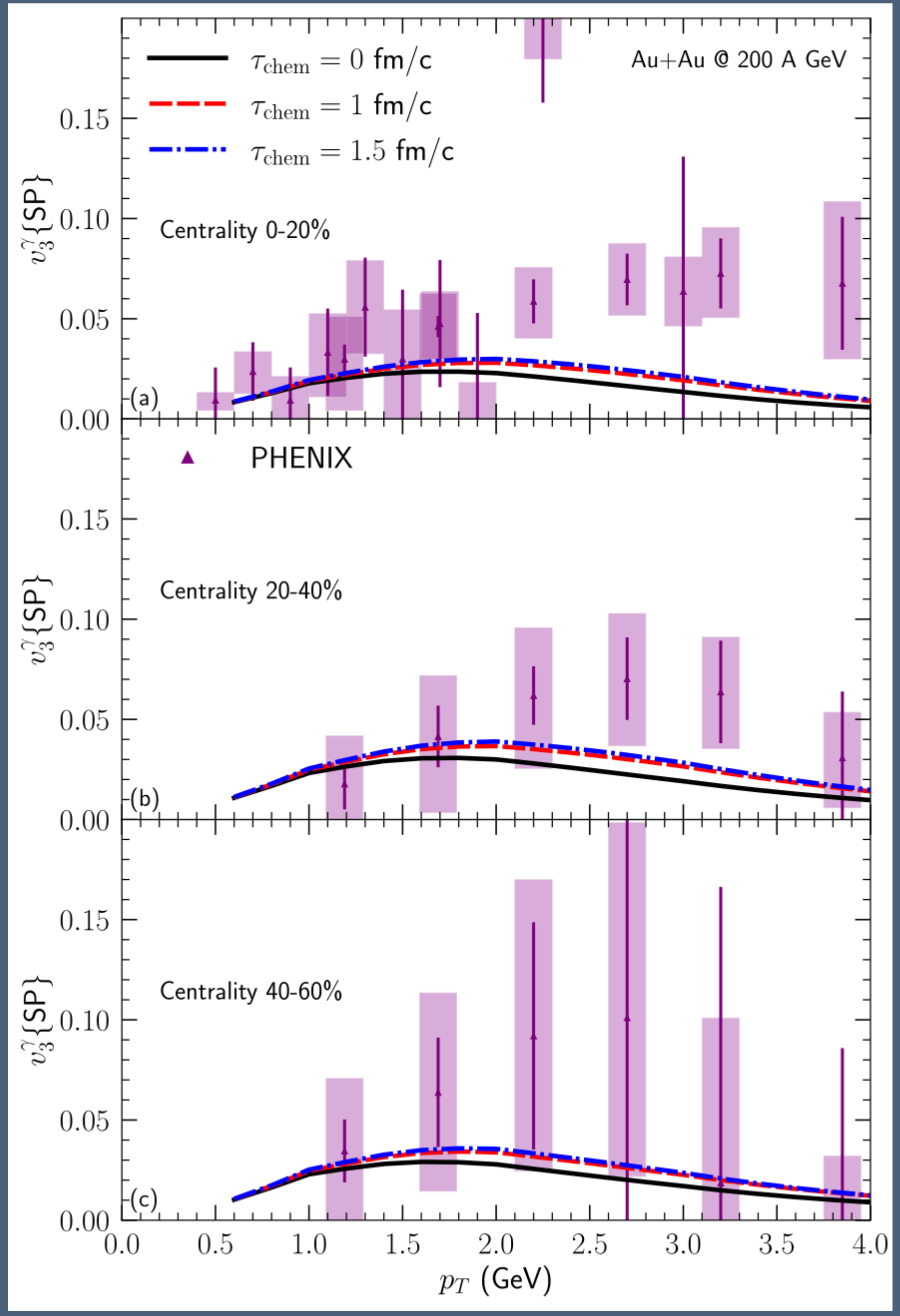


arXiv: 2504.02955

State-of-the-art experimental data and computations

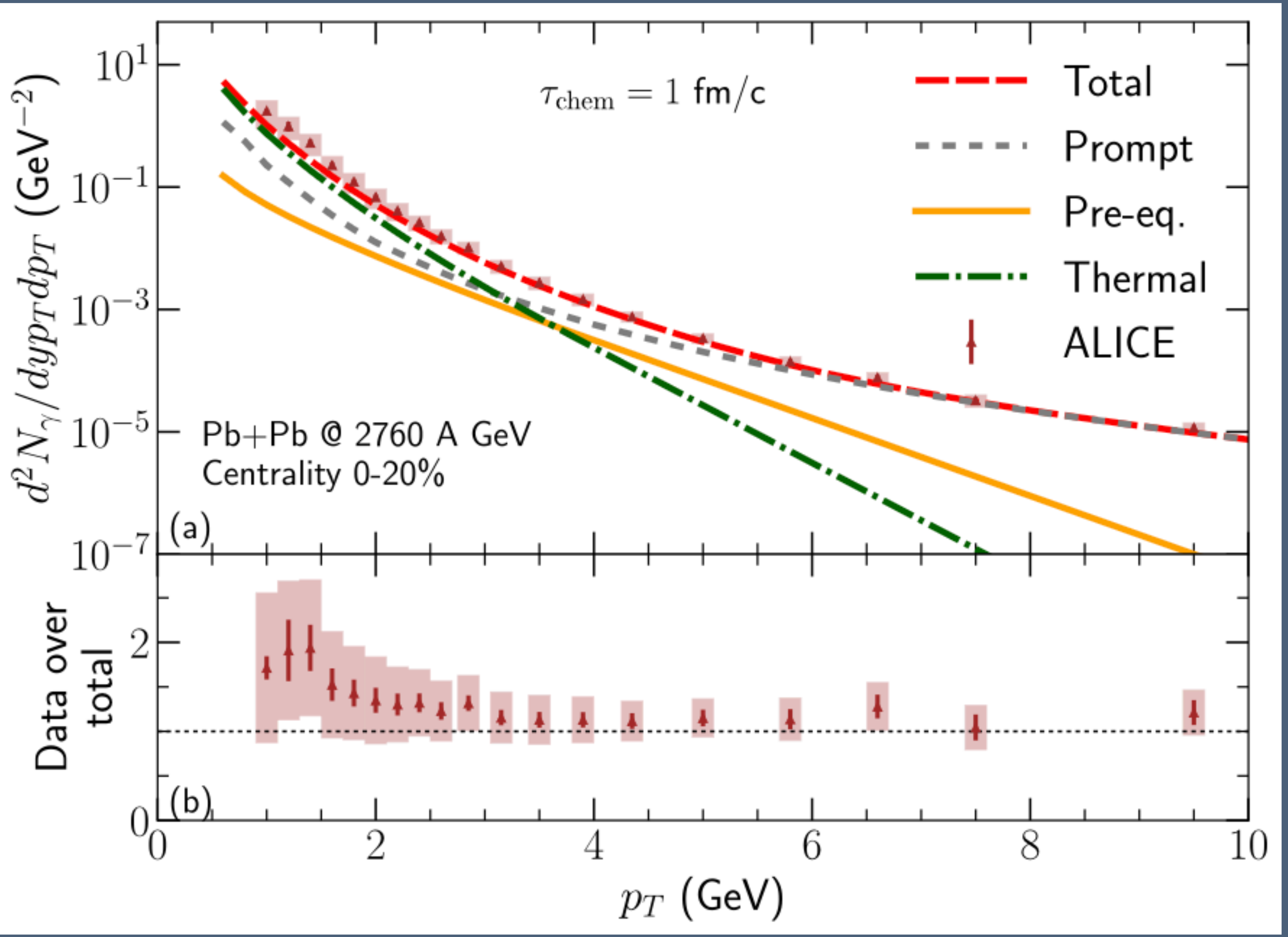
arXiv:2511.08773



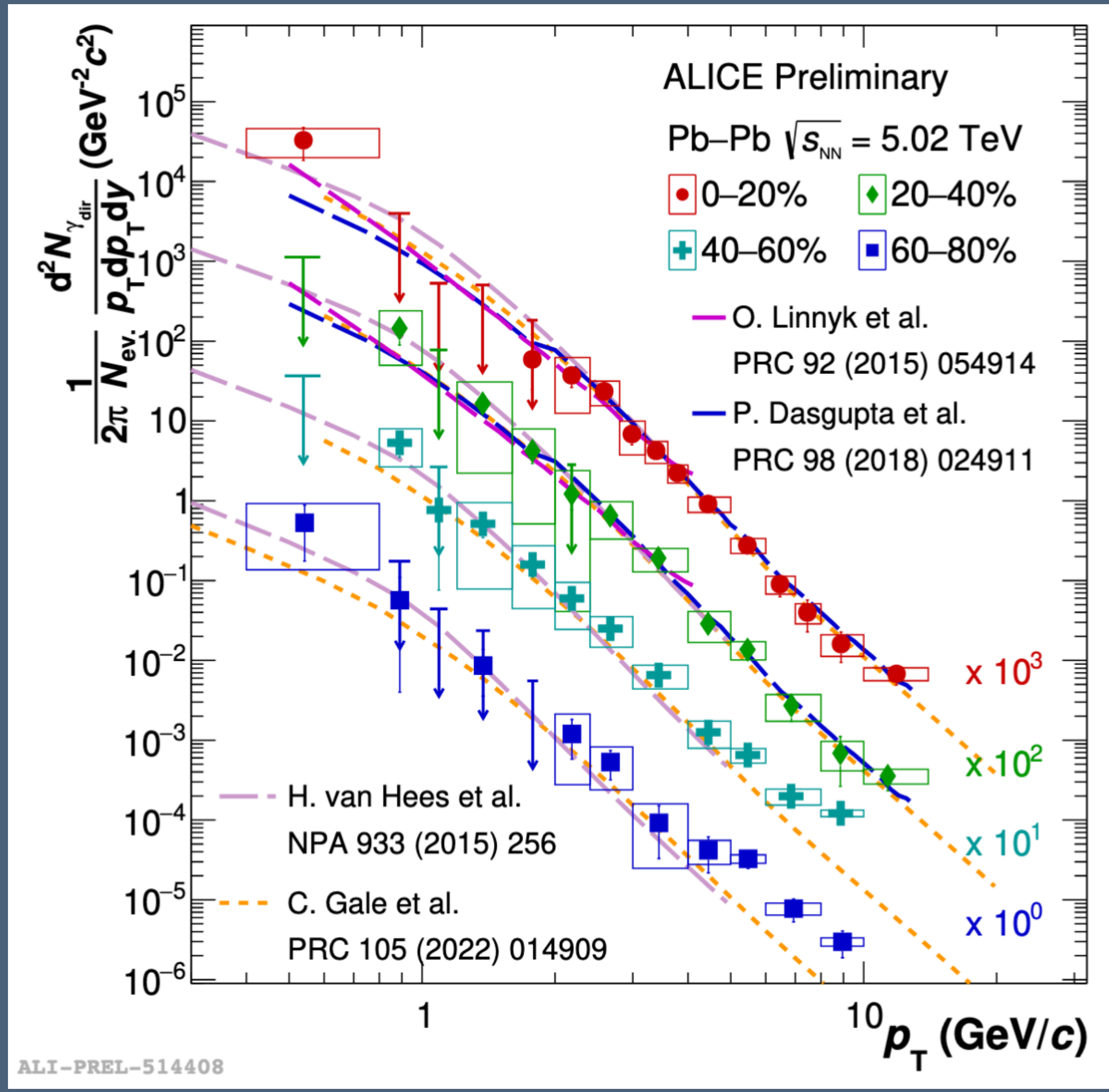


PRC **105**, 014909 (2022)

Photon yield at ALICE energies

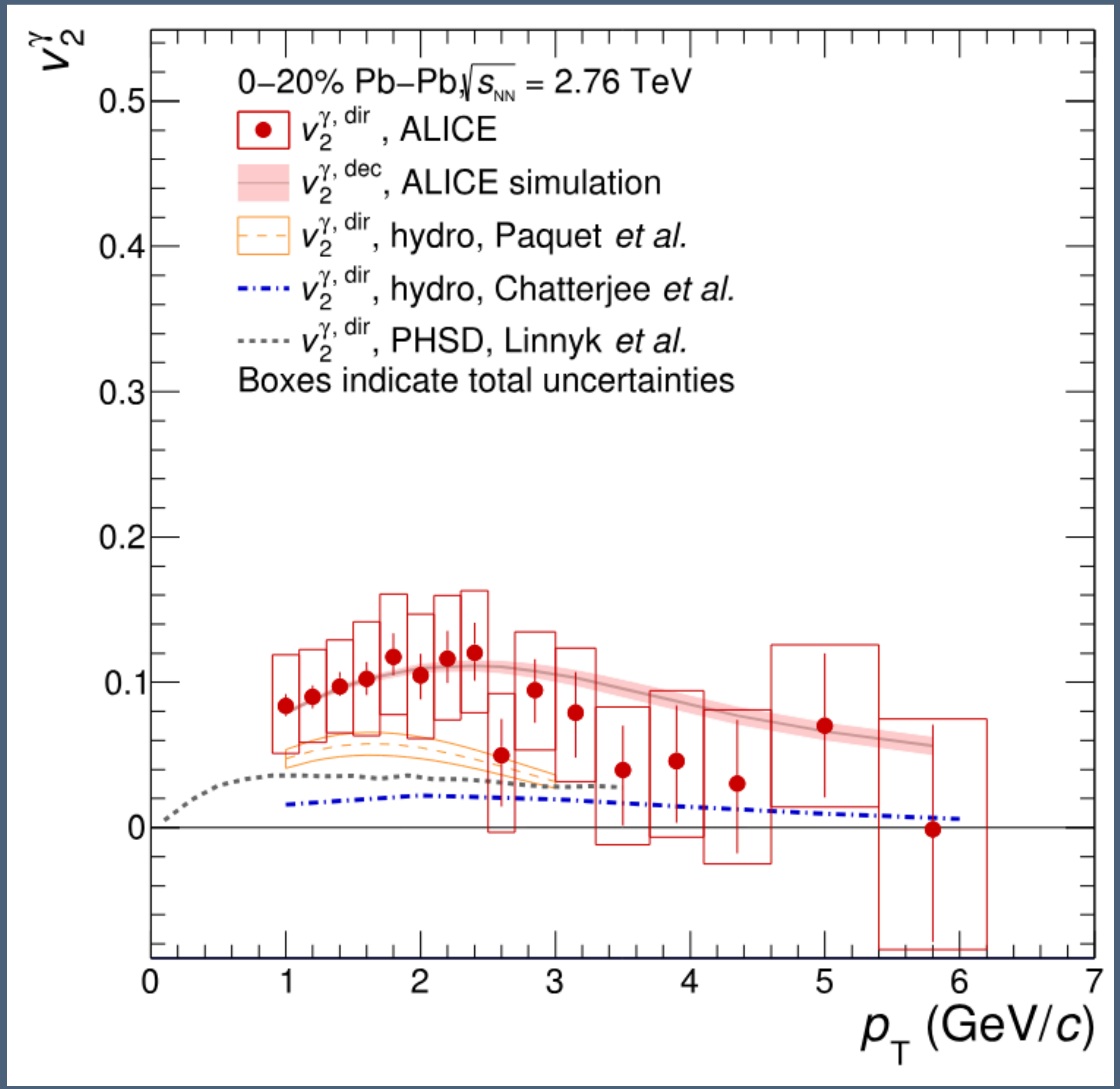


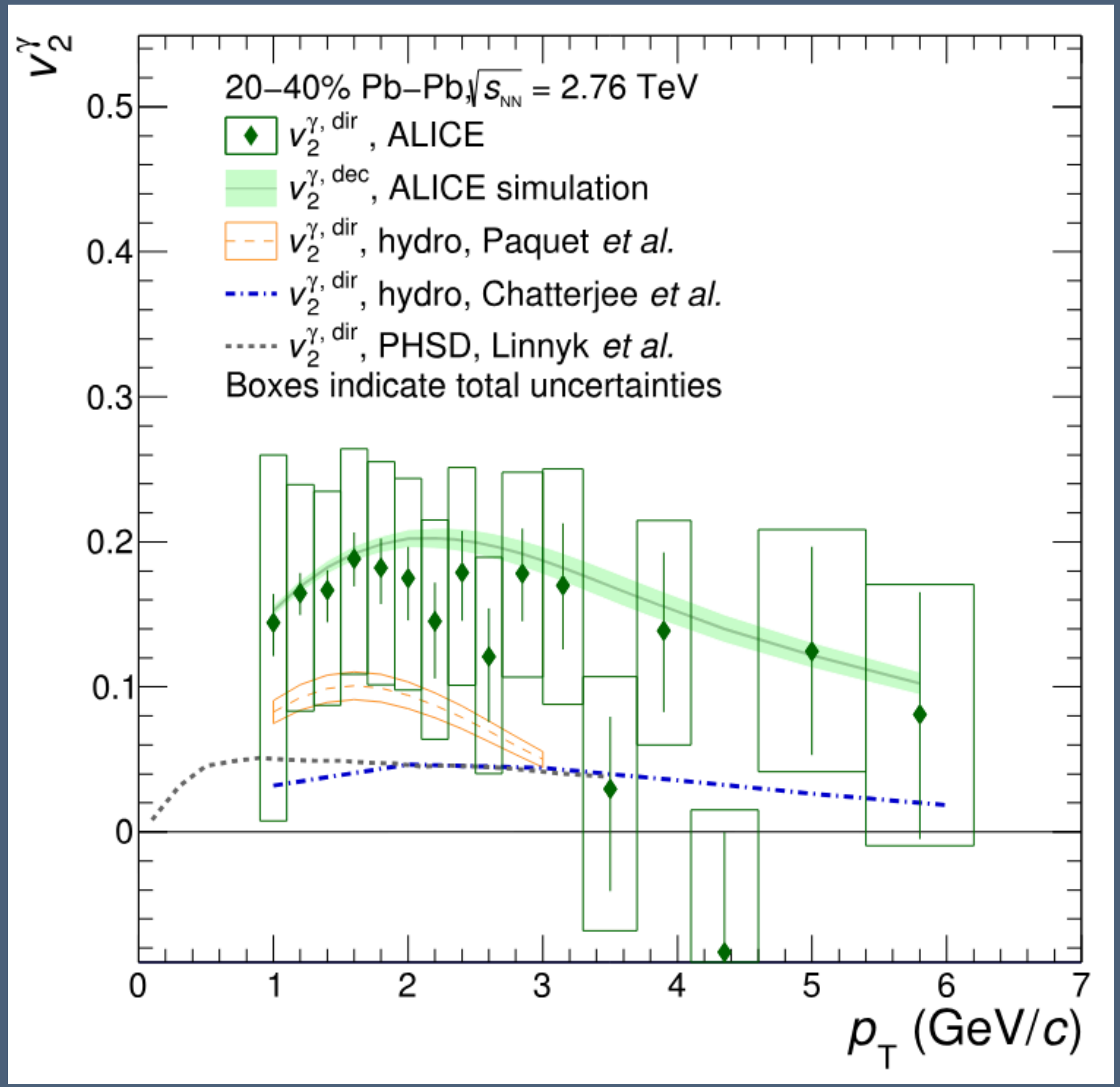
PRC **105**, 014909 (2022)



PoS HardProbes2023 061 (2024)

Photon v_2 at ALICE energies





PLB **789**, 308 (2019)

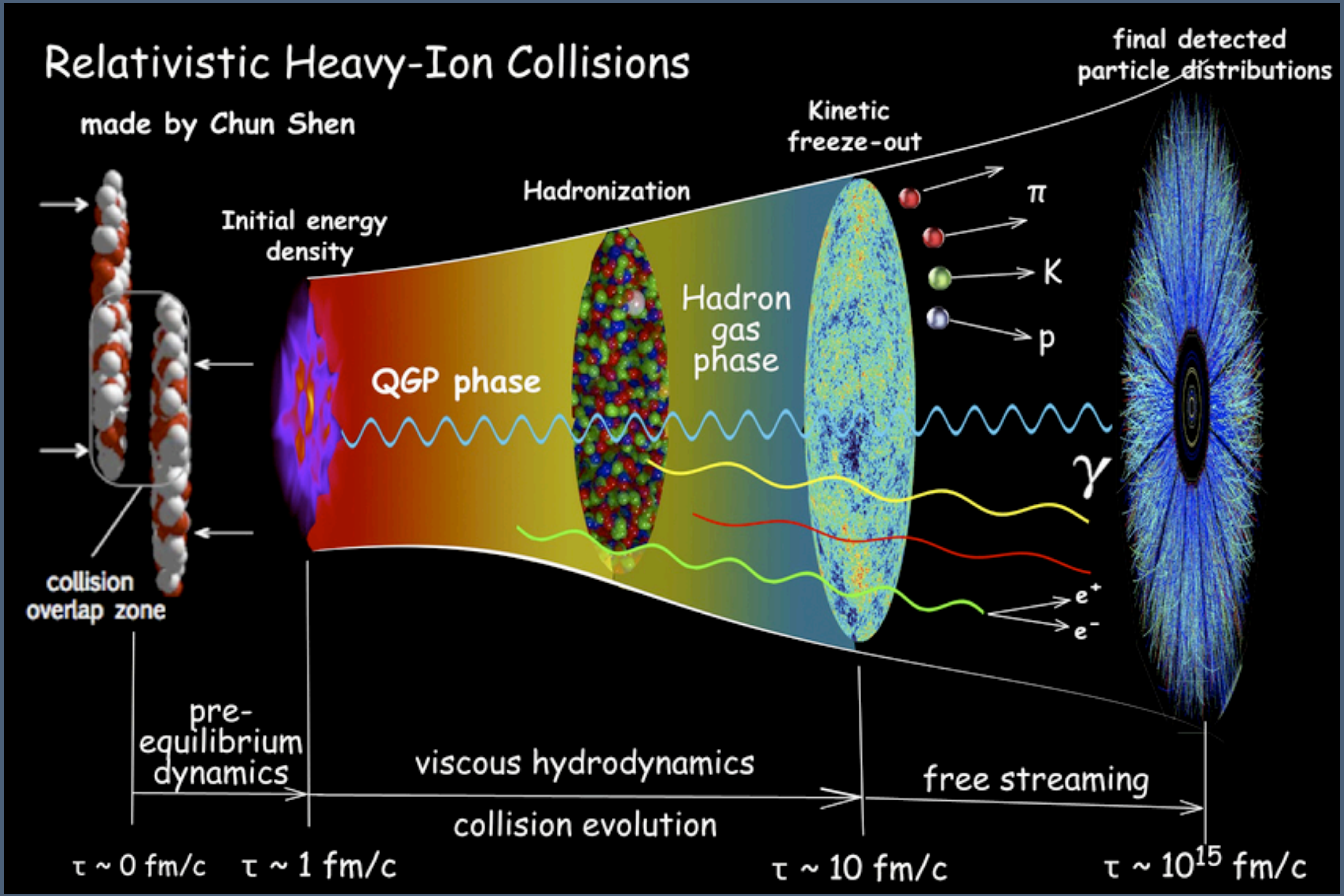
Summary of the photon puzzle

- At RHIC energies ($\sqrt{s_{NN}} = 200$ GeV), the photon puzzle is still difficult to describe. PHENIX confirm a strong low-p_T component and non-zero v_2 that tends to zero at high p_T
- At LHC energies ($\sqrt{s_{NN}} = 2.76 - 5.02$ TeV), results agree, within the errors, to state-of-the-art results.
- Note that there is a tension between PHENIX and STAR results at $\sqrt{s_{NN}} = 200$ GeV (see G. David's talk)

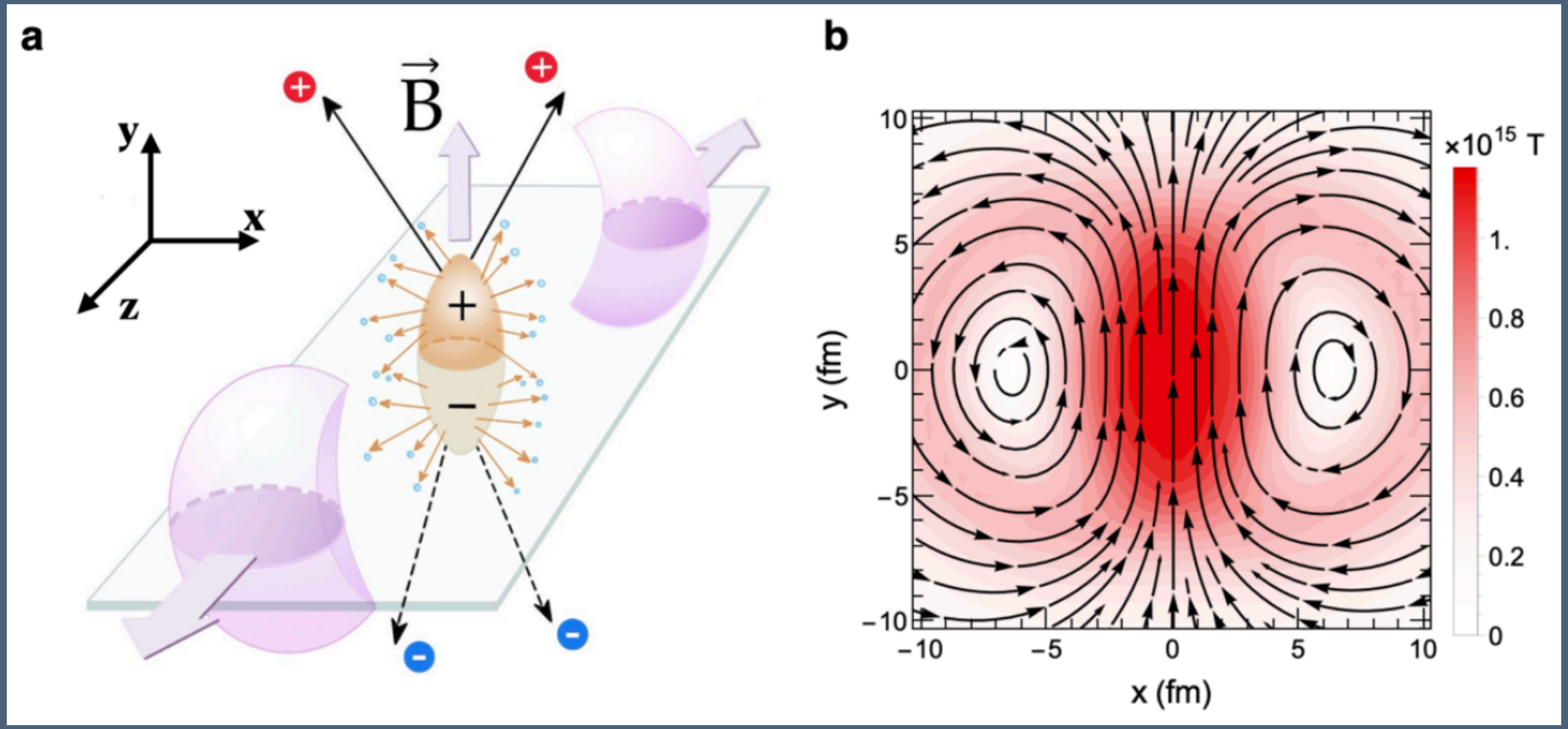
Some possible additional contributions

To the direct photon puzzle

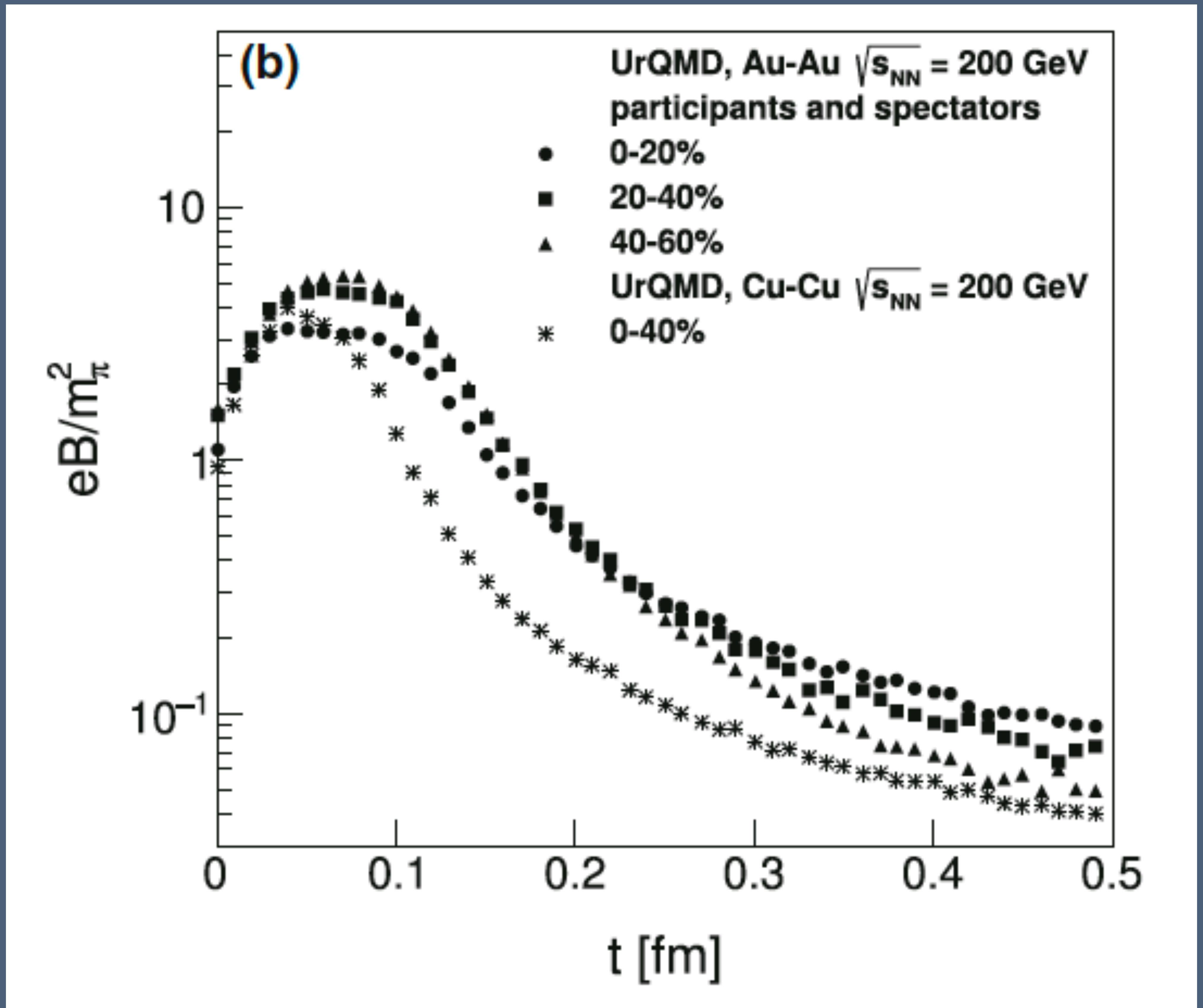
- QCD effective kinetic theory works well at ALICE energies [JHEP **03**, 053 (2024), arXiv:2308.09747]
- Radiative hadronization and hadronic many-body updates (extra late-time photons, larger v_2)
- **Magnetic field related channels!!!** (See E. Muñoz's talk)
- And much more…


Relativistic Heavy-Ion Collisions
made by Chun Shen
final detected particle distributions
Kinetic freeze-out
Hadronization
Initial energy density
Hadron gas phase
QGP phase
π
K
p
γ
e+
e−
collision overlap zone
pre-equilibrium dynamics
viscous hydrodynamics
free streaming
collision evolution
τ ~ 0 fm/c
τ ~ 1 fm/c
τ ~ 10 fm/c
τ ~ 10^15 fm/c

Magnetic fields



Nature Rev. Phys. **3**, 55 (2021), arXiv:2102.06623



EPJ A **56**, 53 (2020), arXiv:1904.02938

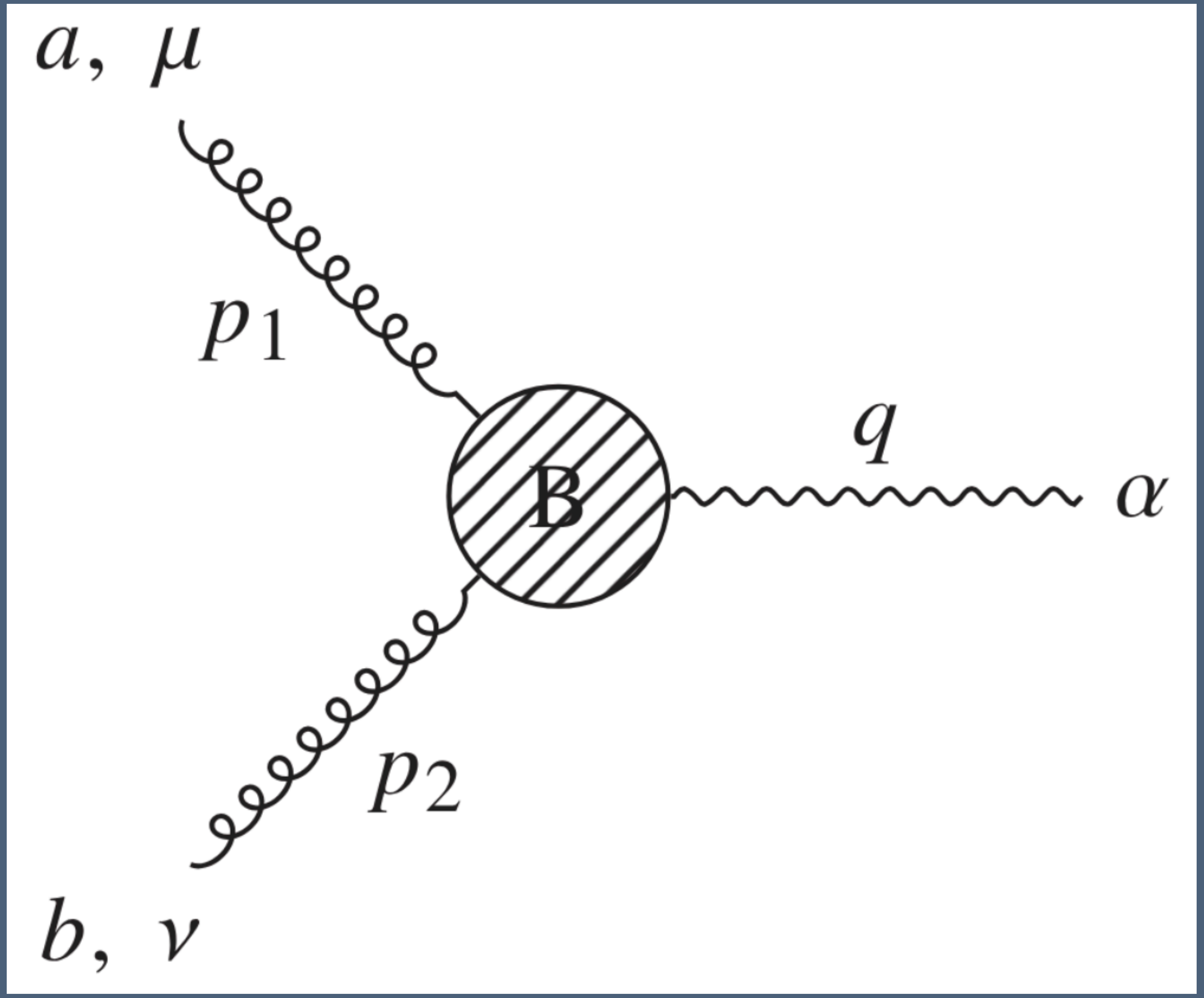
Very short list of magnetic field contributions

- Anomaly-induced photons (QCD × QED conformal anomaly in a B-background) [PRL **109**, 202303 (2012)]
- Holographic methods used to describe photon production from a strongly coupled plasma in the presence of a magnetic field [PRD **107**, 066010 (2023)]
- Photons radiated by $2 \rightarrow 2$ scattering process among quarks and gluons in a weak magnetic field ($eB \sim 10^{-2} m_\pi^2$) in the hydrodynamic stage of a heavy-ion collision [Nucl. Phys. Rev. **41**, 1 (2024)]
- Gluon fusion and splitting at pre-equilibrium in the presence of a strong magnetic field ($eB \sim 3m_\pi^2$) [PRD **96**, 014023 (2017)]
- This strong field approximation is not very appropriate, since we have the following hierarchy of scales: $m_f^2 < |eB| < p_T^2$

Two-gluon one-photon vertex

General structure [PRD 110, 076021 (2024)]

- From gauge invariance, the vertex must be transverse when contracted with the gluons and photons momenta
- The vertex must be symmetric under gluon exchange
- The vertex is invariant under CP
- The basis, known as Ritus Base (see E. Monreal's talk), will be expressed as a set of polarization vectors and the photon's momentum:
- q^μ
- $l_q^\mu \equiv \hat{F}^{\mu\beta} q_\beta$
- $l_q^{*\mu} \equiv \hat{F}^{*\mu\beta} q_\beta$
- $k_q^\mu \equiv \dfrac{q^2}{l_q^2} \hat{F}^{\mu\beta} \hat{F}_{\beta\sigma} q^\sigma + q^\mu$



Furry's theorem does not apply here due to the breaking of Lorentz invariance because of the magnetic field

Two-gluon one-photon vertex

General structure

- Assuming a constant magnetic field in the $\hat{z}$ direction, the polarizations can be explicitly written
- In principle, there are 27 possible tensor structures that can be constructed with q^μ, $\hat{l}_q^{*,\mu}$, $\hat{l}_q^{*,\mu}$ and k_q^μ
- By considering the gluon exchange symmetry, that number is reduced to 18
- Assuming that the gauge bosons are on-shell, then $k_q^\mu \to q^\mu$
- Imposing the conservation of energy-momentum, which implies that the gauge bosons are collinear

Two-gluon one-photon vertex

General structure

- If we write the transformation properties of each coefficient as a_i^{CP} and consider all the possible Lorentz scalars that can be constructed, it is possible to see that odd structures with respect to $\hat{C}$ and $\hat{P}$, are not available to express the on-shell vertex

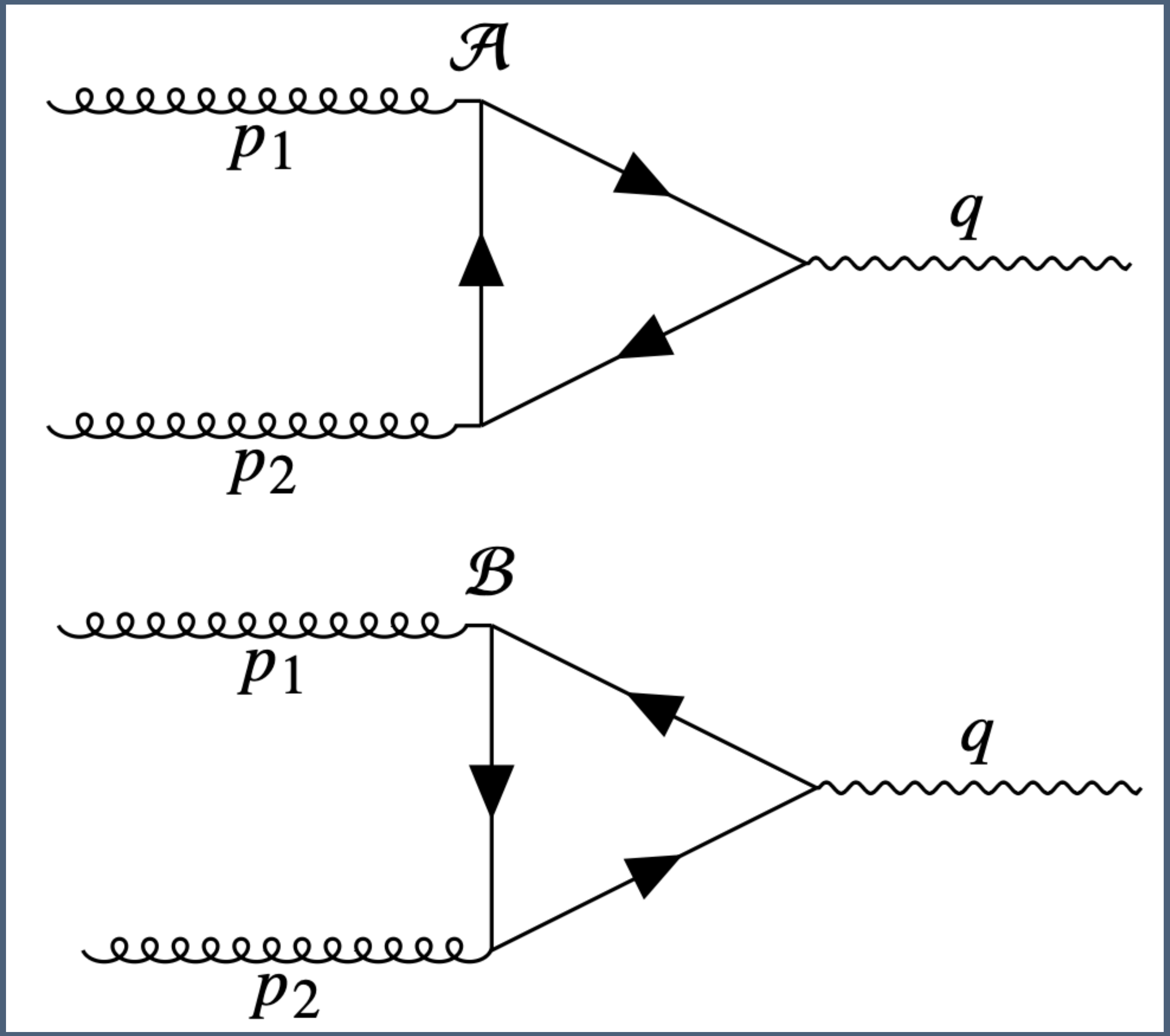
- Hence we arrive at

- $\Gamma^{\mu\nu\alpha}_{ab}(p_1, p_2, q)_{\text{on-shell}} = a_1^{++}\hat{l}^{\mu}_{p_1\,a}\hat{l}^{\nu}_{p_2\,b}\hat{l}^{\alpha}_{q} + a_2^{++}\hat{l}^{*\mu}_{p_1\,a}\hat{l}^{*\nu}_{p_2\,b}\hat{l}^{\alpha}_{q} + \frac{a_{10}^{++}}{\sqrt{2}}\left(\hat{l}^{\mu}_{p_1\,a}\hat{l}^{*\nu}_{p_2\,b} + \hat{l}^{*\mu}_{p_1\,a}\hat{l}^{\nu}_{p_2\,b}\right)\hat{l}^{*\alpha}_{q}$

Two-gluon one-photon vertex

One-loop approximation

- At the leading order in α_s and α_{em}, the vertex is
- $$\Gamma^{\mu\nu\alpha}_{ab} = -ig^2 q_f \int d^4x d^4y d^4z \int \frac{d^4r_1}{(2\pi)^4}\frac{d^4r_2}{(2\pi)^4}\frac{d^4r_3}{(2\pi)^4} \times e^{-ir_3\cdot(y-x)} e^{-ir_2\cdot(x-z)} e^{-ir_1\cdot(z-y)} e^{-ip_1\cdot z} e^{-ip_1\cdot z} e^{-ip_2\cdot y} e^{-ip_3\cdot x} \times \Big\{ \mathrm{Tr}\left[\gamma_\alpha S(r_2)\gamma_\mu t_a S(r_1)\gamma_\nu t_b S(r_3)\right] \Phi(x,y,z,x) \times \mathrm{Tr}\left[\gamma_\alpha S(r_3)\gamma_\nu t_a S(r_1)\gamma_\mu t_b S(r_2)\right] \Phi(x,z,y,x) \Big\}$$
- Where $\Phi(x,y,z,x)$ is the product of Schwinger phases and
- $$S(p) = \int_0^\infty \frac{ds}{\cos(q_f Bs)} e^{is\left(p_\parallel^2 + p_\perp^2 \frac{\tan(q_f Bs)}{q_f Bs} - m_f^2 + i\epsilon\right)} \left[e^{iq_f Bs\Sigma_3}(m_f + \not{p}_\parallel) + \frac{\not{p}_\perp}{\cos(q_f Bs)} \right]$$



Two-gluon one-photon vertex

One-loop approximation

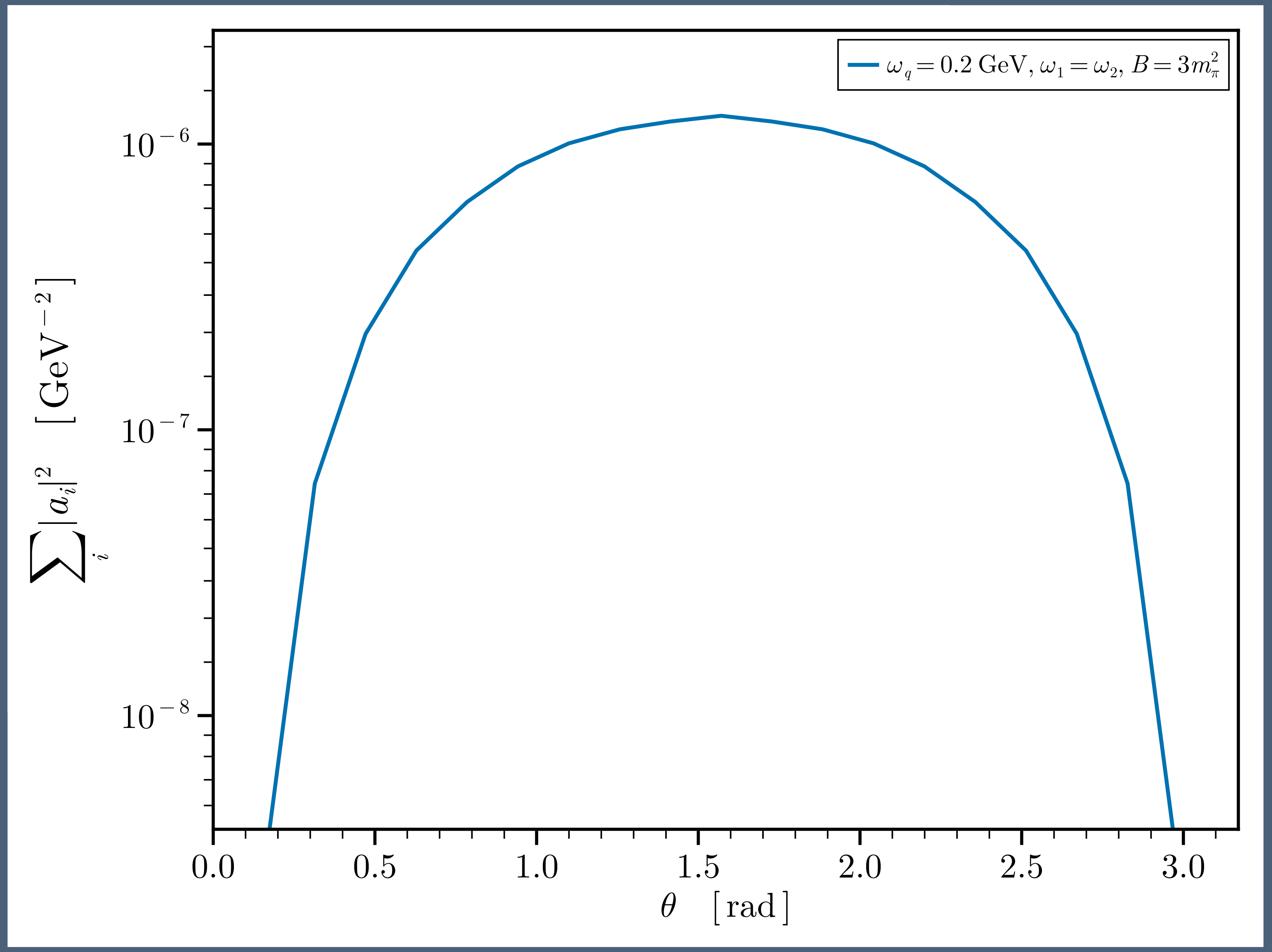
- In the on-shell limit, the vertex is
- $$\Gamma^{\mu\nu\alpha}_{ab} = -i\frac{g^2q_f^2B}{2\pi^2}\mathrm{Tr}[t_at_b]\delta^4(p_1+p_2-q) \times \int_0^\infty \frac{ds_1ds_2ds_3}{c_1^2c_2^2c_3^2}\left(\frac{1}{t_1t_2t_3-t_1-t_2-t_3}\right)\left(\frac{e^{-ism_f^2}}{s}\right) \times e^{-\frac{i}{s}(s_1s_3\omega_{p_1}^2+s_2s_3\omega_{p_2}^2+s_1s_2\omega_q^2)\frac{q_\perp^2}{\omega_q^2}} \times e^{-\frac{i}{\omega_q^2}\frac{q_\perp^2}{|q_fB|}\left(\frac{1}{t_1t_2t_3-t_1-t_2-t_3}\right)(t_1t_3\omega_{p_1}^2+t_2t_3\omega_{p_2}^2+t_1t_2\omega_q^2)} \times \sum_{j=1}^{19}\left(T^{\mu\nu\alpha}_{\mathscr{A}_j}+T^{\mu\nu\alpha}_{\mathscr{B}_j}\right)$$

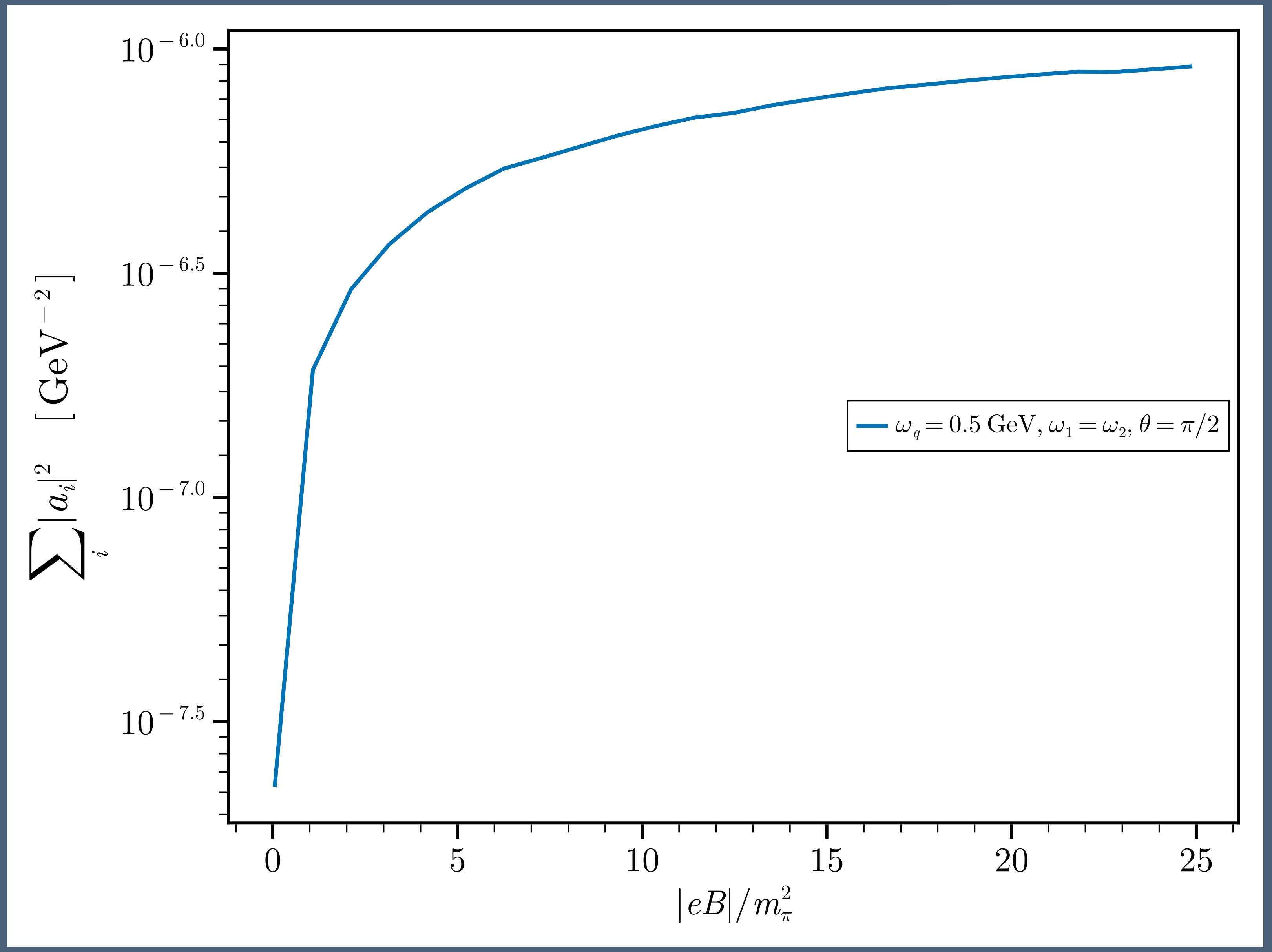
$$T^{\mu\nu\alpha}_{\mathcal{A}1}+T^{\mu\nu\alpha}_{\mathcal{B}1} = \mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu\not{\mathcal{A}}_c]+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha\not{\mathcal{B}}_a],$$
$$T^{\mu\nu\alpha}_{\mathcal{A}2}+T^{\mu\nu\alpha}_{\mathcal{B}2} = m_f^2\{\mathrm{Tr}[\gamma^\mu e_1\gamma^\alpha e_2\gamma^\nu\not{\mathcal{A}}_c]+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu e_2\gamma^\alpha e_1]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}3}+T^{\mu\nu\alpha}_{\mathcal{B}3} = m_f^2\{\mathrm{Tr}[\gamma^\mu e_1\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu e_3]+\mathrm{Tr}[\gamma^\mu e_3\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha e_1]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}4}+T^{\mu\nu\alpha}_{\mathcal{B}4} = m_f^2\{\mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha e_2\gamma^\nu e_3]+\mathrm{Tr}[\gamma^\mu e_3\gamma^\nu e_2\gamma^\alpha\not{\mathcal{B}}_a]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}5}+T^{\mu\nu\alpha}_{\mathcal{B}5} = \frac{i}{s}\{\mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha e_2\gamma^\nu_\parallel e_3]+\mathrm{Tr}[\gamma^\mu e_3\gamma^\nu_\parallel e_2\gamma^\alpha\not{\mathcal{B}}_a]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}6}+T^{\mu\nu\alpha}_{\mathcal{B}6} = \frac{i}{s}\{\mathrm{Tr}[\gamma^\mu_\parallel e_1\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu e_3]+\mathrm{Tr}[\gamma^\mu_\parallel e_3\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha e_1]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}7}+T^{\mu\nu\alpha}_{\mathcal{B}7} = \frac{i}{s}\{\mathrm{Tr}[\gamma^\mu e_1\gamma^\alpha_\parallel e_2\gamma^\nu\not{\mathcal{A}}_c]+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu e_2\gamma^\alpha_\parallel e_1]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}8}+T^{\mu\nu\alpha}_{\mathcal{B}8} = -\frac{i}{s}\{\mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha e_2\gamma^\nu e_3]+\mathrm{Tr}[\gamma^\mu e_3\gamma^\nu e_2\gamma^\alpha\not{\mathcal{B}}_a]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}9}+T^{\mu\nu\alpha}_{\mathcal{B}9} = -\frac{i}{s}\{\mathrm{Tr}[\gamma^\mu e_1\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu e_3]+\mathrm{Tr}[\gamma^\mu e_3\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha e_1]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}10}+T^{\mu\nu\alpha}_{\mathcal{B}10} = -\frac{i}{s}\{\mathrm{Tr}[\gamma^\mu e_1\gamma^\alpha e_2\gamma^\nu\not{\mathcal{A}}_c]+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu e_2\gamma^\alpha e_1]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}11}+T^{\mu\nu\alpha}_{\mathcal{B}11} = \frac{iq_fB}{(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha\gamma^\nu]+\mathrm{Tr}[\gamma^\mu\gamma^\nu\gamma^\alpha\not{\mathcal{B}}_a]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}12}+T^{\mu\nu\alpha}_{\mathcal{B}12} = \frac{iq_fB}{(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu]+\mathrm{Tr}[\gamma^\mu\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}13}+T^{\mu\nu\alpha}_{\mathcal{B}13} = \frac{iq_fB}{(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\gamma^\alpha\gamma^\nu\not{\mathcal{A}}_c]+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu\gamma^\alpha]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}14}+T^{\mu\nu\alpha}_{\mathcal{B}14} = -\frac{iq_fB}{(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha\gamma^\nu_\perp]+\mathrm{Tr}[\gamma^\mu\gamma^\nu_\perp\gamma^\alpha\not{\mathcal{B}}_a]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}15}+T^{\mu\nu\alpha}_{\mathcal{B}15} = -\frac{iq_fB}{(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu_\perp\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu]+\mathrm{Tr}[\gamma^\mu_\perp\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}16}+T^{\mu\nu\alpha}_{\mathcal{B}16} = -\frac{iq_fB}{(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\gamma^\alpha_\perp\gamma^\nu\not{\mathcal{A}}_c]+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu\gamma^\alpha_\perp]\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}17}+T^{\mu\nu\alpha}_{\mathcal{B}17} = \frac{iq_fBt_1}{2(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\not{\mathcal{A}}_a\gamma^\alpha\gamma^\beta_\perp\gamma^\nu\gamma^\sigma_\perp]\hat{F}_{\beta\sigma}+\mathrm{Tr}[\gamma^\mu\gamma^\sigma_\perp\gamma^\nu\gamma^\beta_\perp\gamma^\alpha\not{\mathcal{B}}_a]\hat{F}_{\sigma\beta}\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}18}+T^{\mu\nu\alpha}_{\mathcal{B}18} = -\frac{iq_fBt_2}{2(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\gamma^\beta_\perp\gamma^\alpha\not{\mathcal{A}}_b\gamma^\nu\gamma^\sigma_\perp]\hat{F}_{\beta\sigma}+\mathrm{Tr}[\gamma^\mu\gamma^\sigma_\perp\gamma^\nu\not{\mathcal{B}}_b\gamma^\alpha\gamma^\beta_\perp]\hat{F}_{\sigma\beta}\},$$
$$T^{\mu\nu\alpha}_{\mathcal{A}19}+T^{\mu\nu\alpha}_{\mathcal{B}19} = \frac{iq_fBt_3}{2(t_1t_2t_3-t_1-t_2-t_3)}\{\mathrm{Tr}[\gamma^\mu\gamma^\beta_\perp\gamma^\alpha\gamma^\sigma_\perp\gamma^\nu\not{\mathcal{A}}_c]\hat{F}_{\beta\sigma}+\mathrm{Tr}[\gamma^\mu\not{\mathcal{B}}_c\gamma^\nu\gamma^\sigma_\perp\gamma^\alpha\gamma^\beta_\perp]\hat{F}_{\sigma\beta}\},$$
$$\not{\mathcal{A}}_a = -\left(\frac{s_3\omega_{p_1}+s_2\omega_q}{s\omega_q}\right)\not{q}_\parallel e_1+\frac{(t_3\omega_{p_1}+t_2\omega_q)\not{q}_\perp-t_2t_3\omega_{p_2}\gamma^\sigma\hat{F}_{\sigma\beta}q^\beta_\perp}{(t_1t_2t_3-t_1-t_2-t_3)\omega_q}$$
$$\not{\mathcal{A}}_b = \left(\frac{s_1\omega_q+s_3\omega_{p_2}}{s\omega_q}\right)\not{q}_\parallel e_2-\frac{(t_3\omega_{p_2}+t_1\omega_q)\not{q}_\perp+t_1t_3\omega_{p_1}\gamma^\sigma\hat{F}_{\sigma\beta}q^\beta_\perp}{(t_1t_2t_3-t_1-t_2-t_3)\omega_q}$$
$$\not{\mathcal{A}}_c = \left(\frac{s_1\omega_{p_1}-s_2\omega_{p_2}}{s\omega_q}\right)\not{q}_\parallel e_3+\frac{(-t_1\omega_{p_1}+t_2\omega_{p_2})\not{q}_\perp+t_1t_3\omega_q\gamma^\sigma\hat{F}_{\sigma\beta}q^\beta_\perp}{(t_1t_2t_3-t_1-t_2-t_3)\omega_q}$$
$$\not{\mathcal{B}}_a = \left(\frac{s_3\omega_{p_1}+s_2\omega_q}{s\omega_q}\right)\not{q}_\parallel e_1-\frac{(t_3\omega_{p_1}+t_2\omega_q)\not{q}_\perp+t_2t_3\omega_{p_2}\gamma^\sigma\hat{F}_{\sigma\beta}q^\beta_\perp}{(t_1t_2t_3-t_1-t_2-t_3)\omega_q}$$

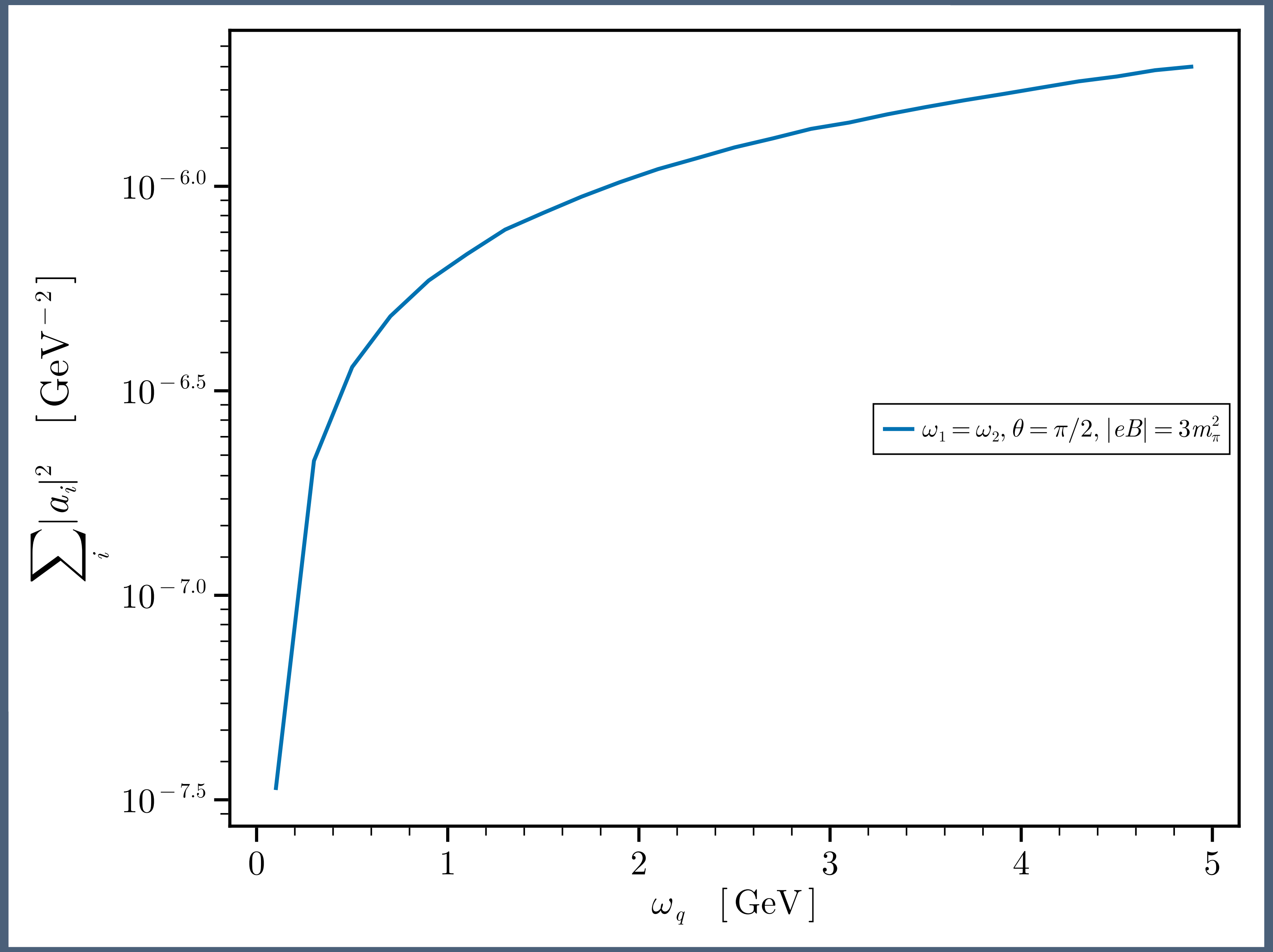
$$\not{\mathcal{B}}_b = -\left(\frac{s_1\omega_q+s_3\omega_{p_2}}{s\omega_q}\right)\not{q}_\parallel e_2+\frac{(t_3\omega_{p_2}+t_1\omega_q)\not{q}_\perp-t_1t_3\omega_{p_1}\gamma^\sigma\hat{F}_{\sigma\beta}q^\beta_\perp}{(t_1t_2t_3-t_1-t_2-t_3)\omega_q}$$
$$\not{\mathcal{B}}_c = -\left(\frac{s_1\omega_{p_1}-s_2\omega_{p_2}}{s\omega_q}\right)\not{q}_\parallel e_3+\frac{(t_1\omega_{p_1}-t_2\omega_{p_2})\not{q}_\perp+t_1t_3\omega_q\gamma^\sigma\hat{F}_{\sigma\beta}q^\beta_\perp}{(t_1t_2t_3-t_1-t_2-t_3)\omega_q}.$$

Vertex coefficients

As a function of the angle, magnetic field and photon's energy



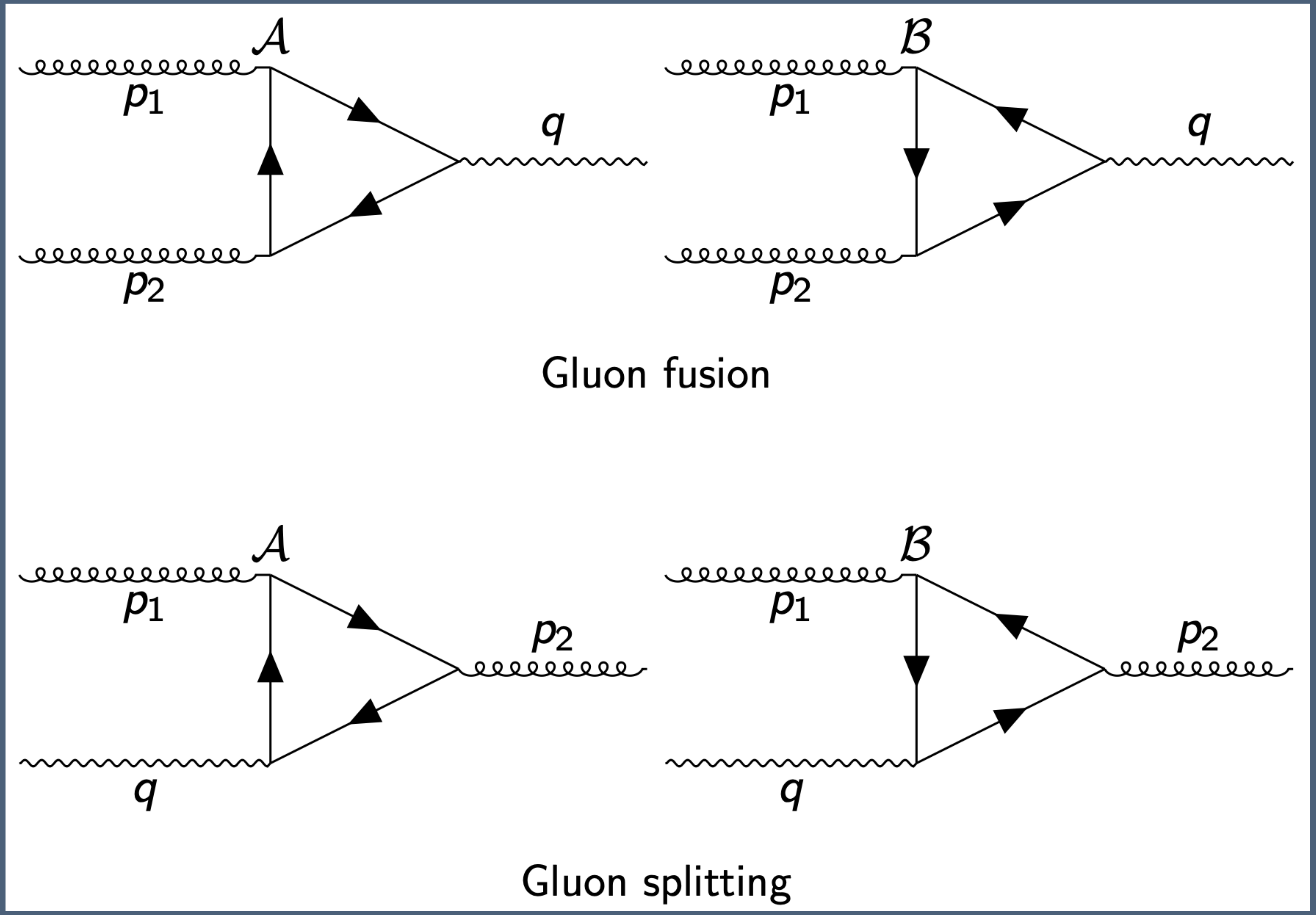




Gluon fusion and gluon splitting

Magnetic contribution to the photon yield

- Both processes can be studied with the same vertex that we already computed, and are related to each other by crossing symmetry
- Each process will contribute to the photon yield
- To compute the yield, we need to know the gluons distribution

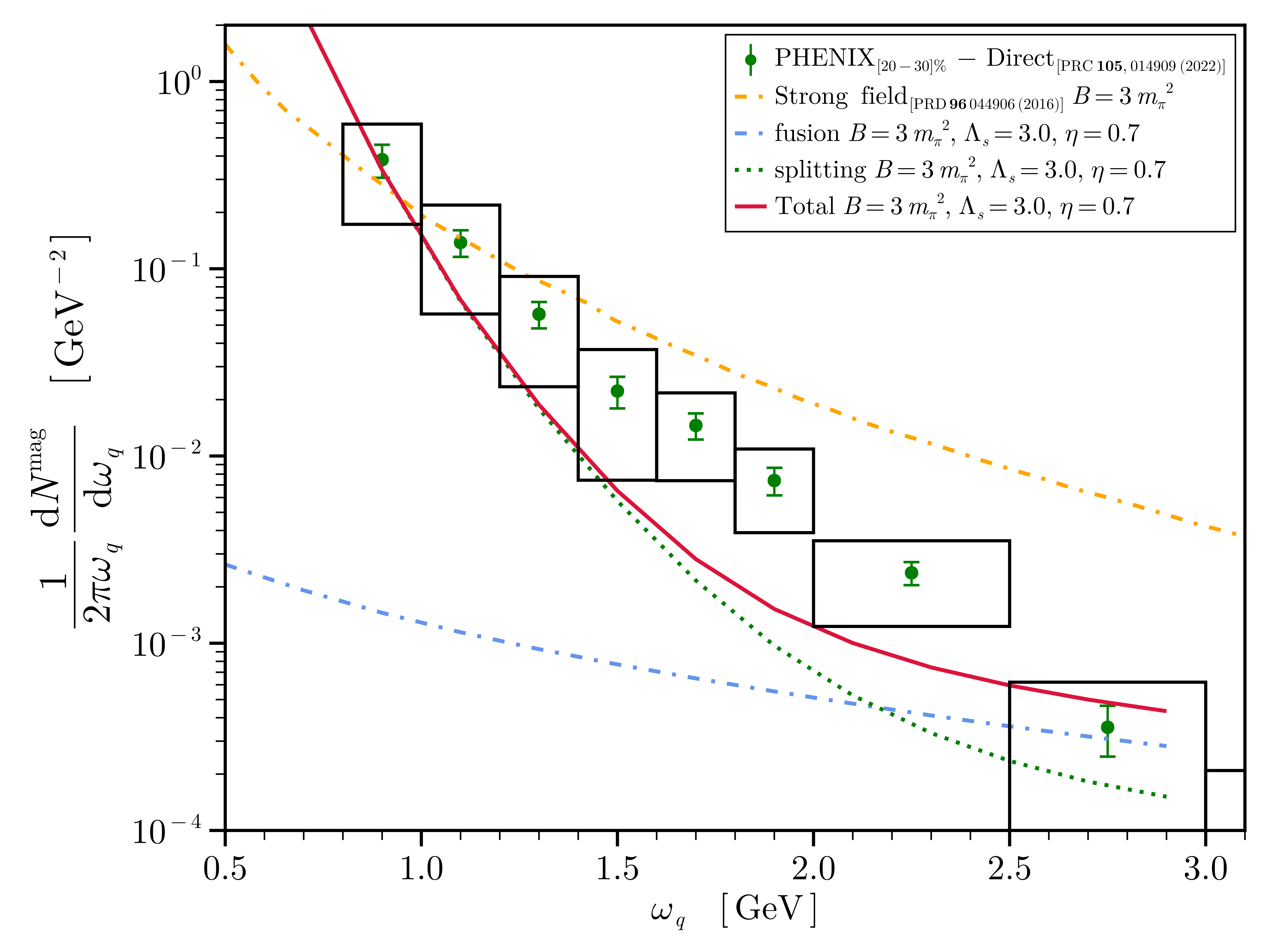


Invariant photon momentum distribution

- $$\omega_q \frac{\mathrm{d}N^{\mathrm{mag}}}{\mathrm{d}^3 q} = \frac{\mathscr{V}\tau}{2(2\pi)^3} \int \frac{d^3 p_1}{(2\pi)^3 2p_1} \frac{d^3 p_2}{(2\pi)^3 2p_2} (2\pi)^4 \Bigg[f(\omega_{p_1}) f(\omega_{p_2}) \delta^{(4)}(q - p_1 - p_2) \frac{1}{4} \sum_i |\Gamma_{gg\to\gamma}|^2 + f(\omega_{p_1})(1 + f(\omega_{p_2})) \delta^{(4)}(q + p_1 - p_2) \frac{1}{4} \sum_i |\Gamma_{g\to g\gamma}|^2 \Bigg]$$
- $f(\omega)$ is an **isotropic** distribution of gluons from the shattered glasma
- $f(\omega) = \dfrac{\eta}{e^{\omega/\Lambda_s} - 1}$
- where η and Λ_s represent a high gluon occupation factor and saturation momentum, respectively

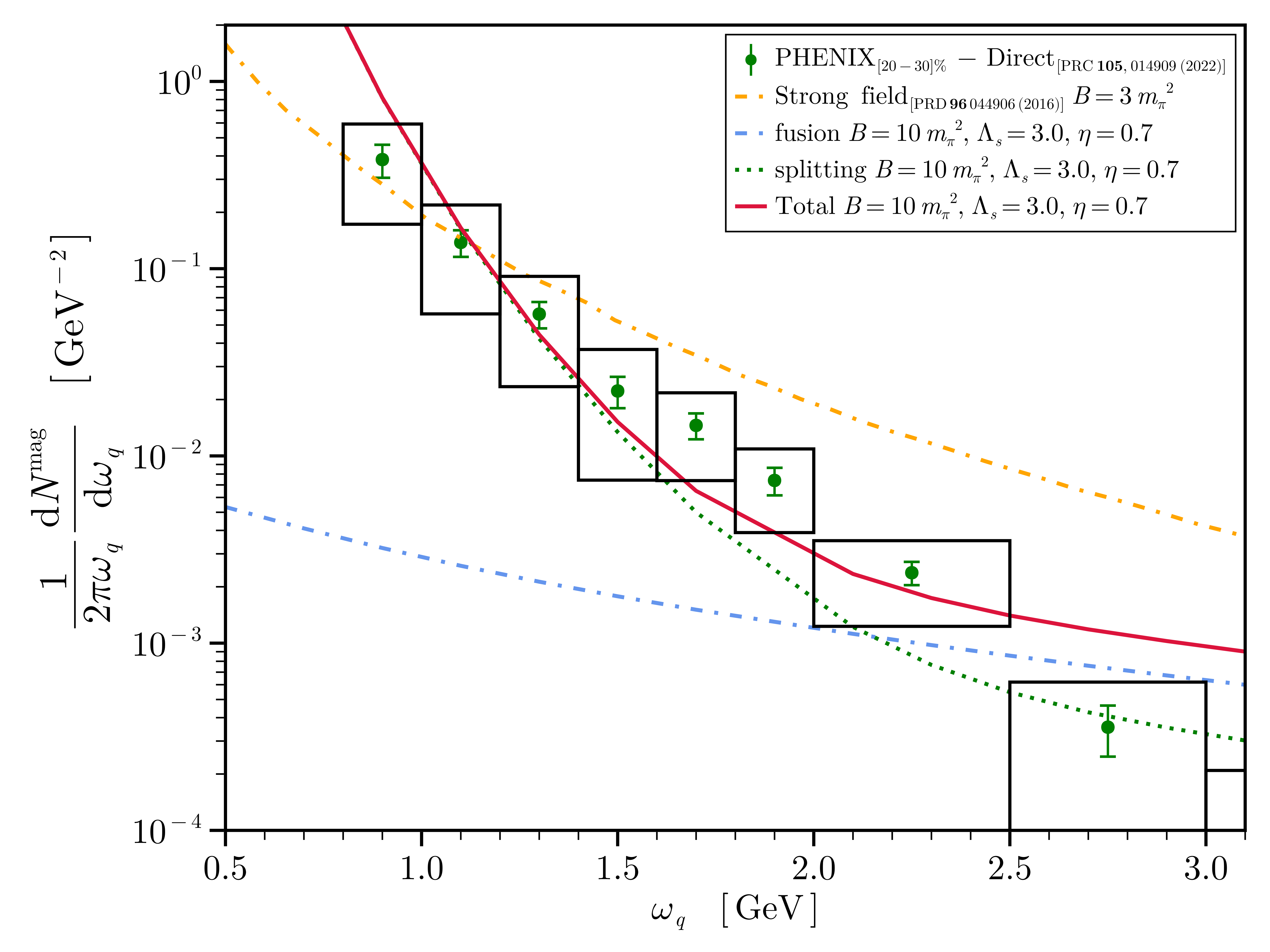
Excess photon compared to PHENIX

$(y = 0, B = 3m_\pi^2)$



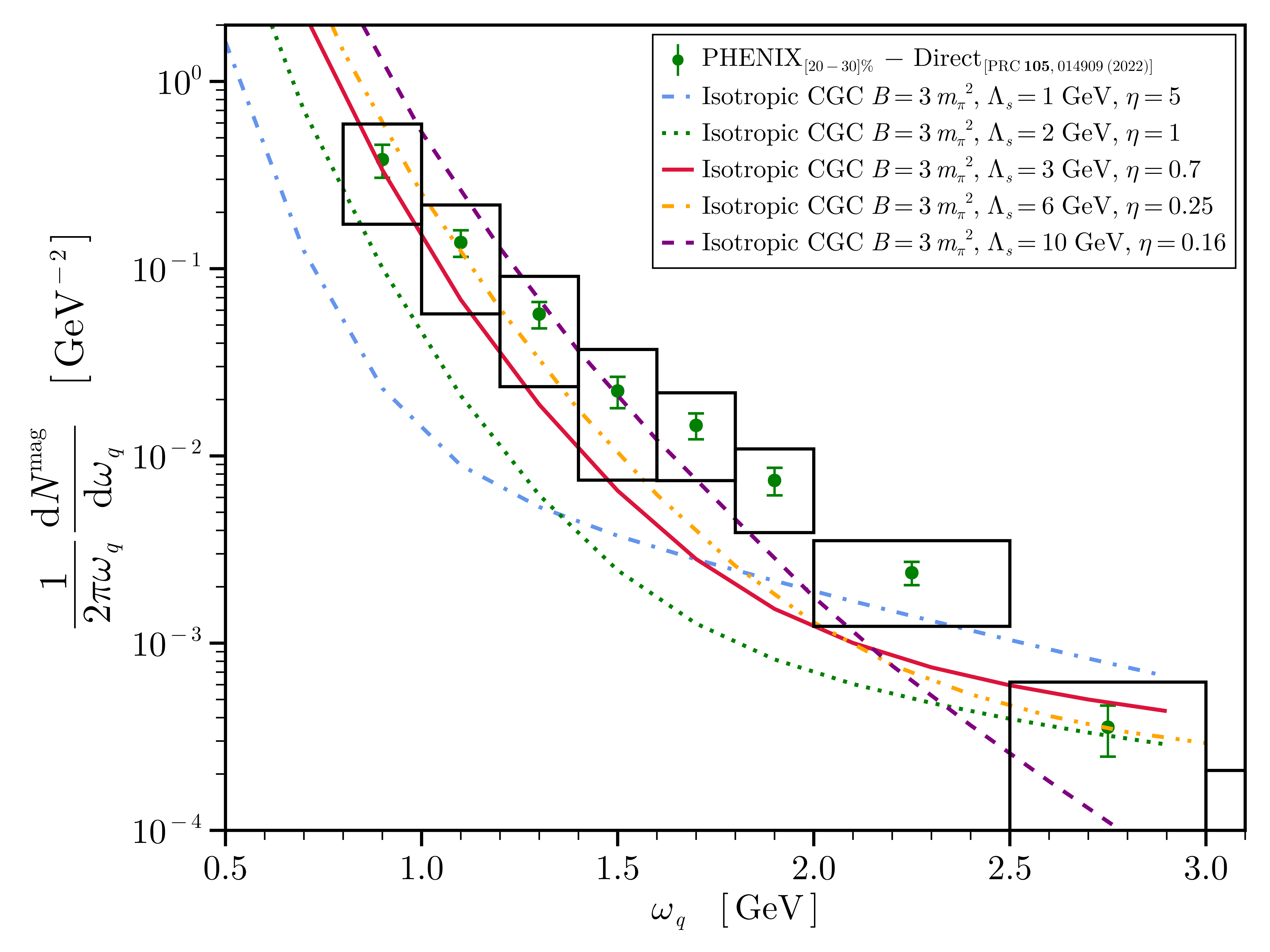
Excess photon compared to PHENIX

$(y = 0, B = 10m_\pi^2)$



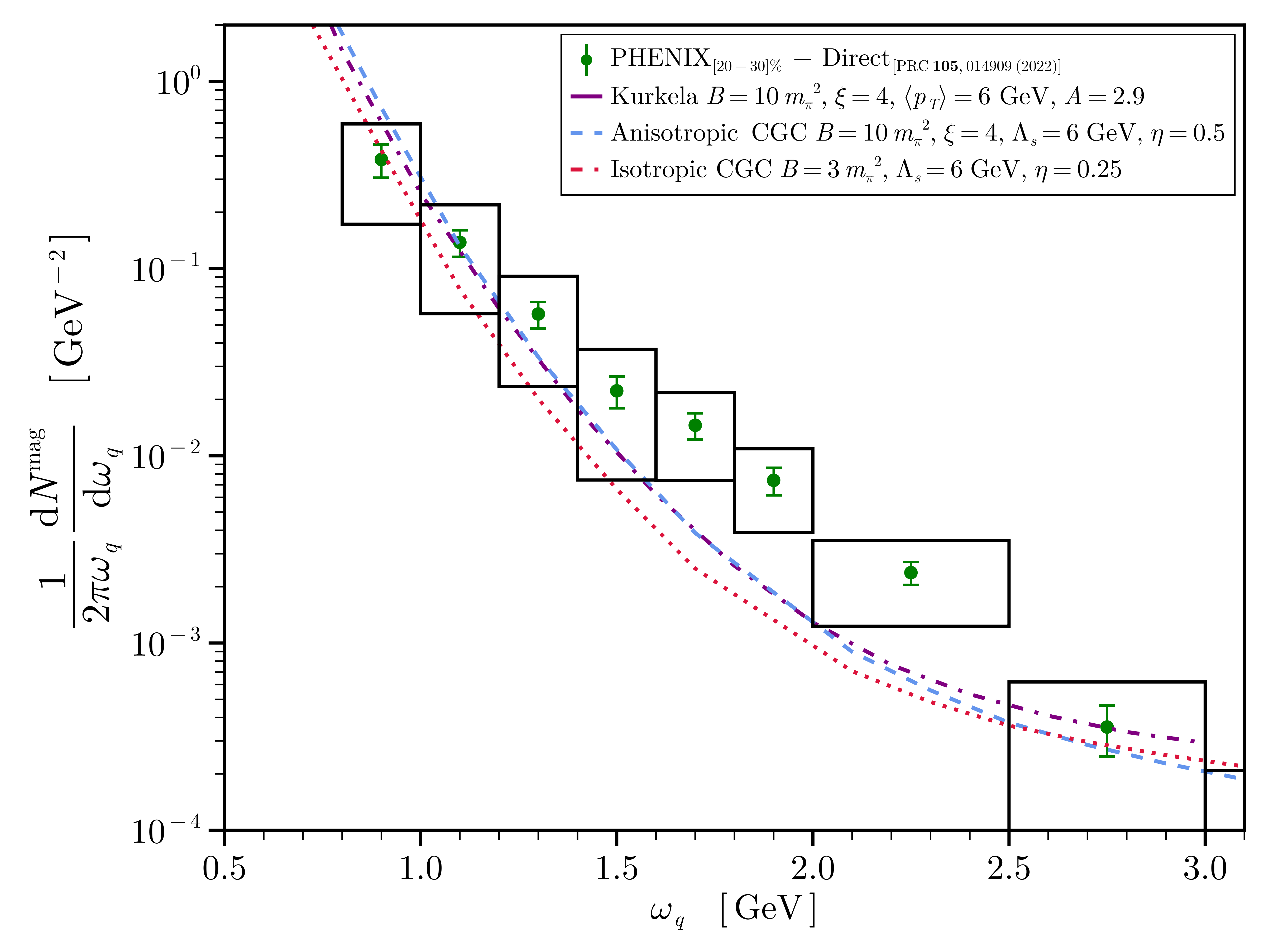
Excess photon compared to PHENIX

$(y = 0, B = 3m_\pi^2)$



Test possible initial anisotropy

- We can include this asymmetry in the CGC distribution like
- $$f(\omega) = \frac{\eta}{e^{\sqrt{\xi^2 p_L^2 + p_\perp^2}/\Lambda_s} - 1}$$
- Or use the initial-state distribution of PRL **115**, 182301 (2015)
- $$f(p_L, p_\perp) = A\langle p_T\rangle \frac{e^{-2(\xi^2 p_L^2 + p_\perp^2)/3\langle p_T\rangle^2}}{\sqrt{\xi^2 p_L^2 + p_\perp^2}}$$



Summary and conclusions

- We found the general structure of the two-gluon one-photon vertex in the presence of a constant magnetic field and use it to compute, at one-loop level the gluon fusion and gluon splitting channels for photon production
- Preliminary results on photon yield excess better described with magnetic field effects at low energies
- Currently working on v_2 and v_3
- Stay tuned!

Thank you !

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Backup

Why there are not $\hat{C}$ and $\hat{P}$-odd scalars

In the tensor structure?

- To write the coefficients a_i, $i = 1,\ldots,18$, we have at our disposal Lorentz scalars also with definite properties under $\hat{C}$ and $\hat{P}$. Expressing any of the momentum variables as p_m^μ, the available scalars are:
- $S_{1\,mn}^{++} = (p_m \cdot p_n)$, $S_{2\,mn}^{++} = (p_m \cdot p_n)_\perp$, $S_{3\,mn}^{-+} = p_m^\mu \hat{F}_{\mu\nu} p_n^\nu$, $S_{4\,mn}^{--} = p_m^\mu \hat{F}^*_{\mu\nu} p_n^\nu$
- For on-shell bosons, conservation of energy implies that we have $p_1^\mu = \left(\frac{\omega_{p_1}}{\omega_q}\right) q^\mu$ and $p_2^\mu = \left(\frac{\omega_{p_2}}{\omega_q}\right) q^\mu$, and so the Lorentz scalars must be:
- $S_{1\,mn}^{++} = 0$, $S_{2\,mn}^{++} = \left(\frac{\omega_m \omega_n}{\omega_q^2}\right) q_\perp^2$, $S_{3\,mn}^{-+} = 0$, $S_{4\,mn}^{--} = 0$

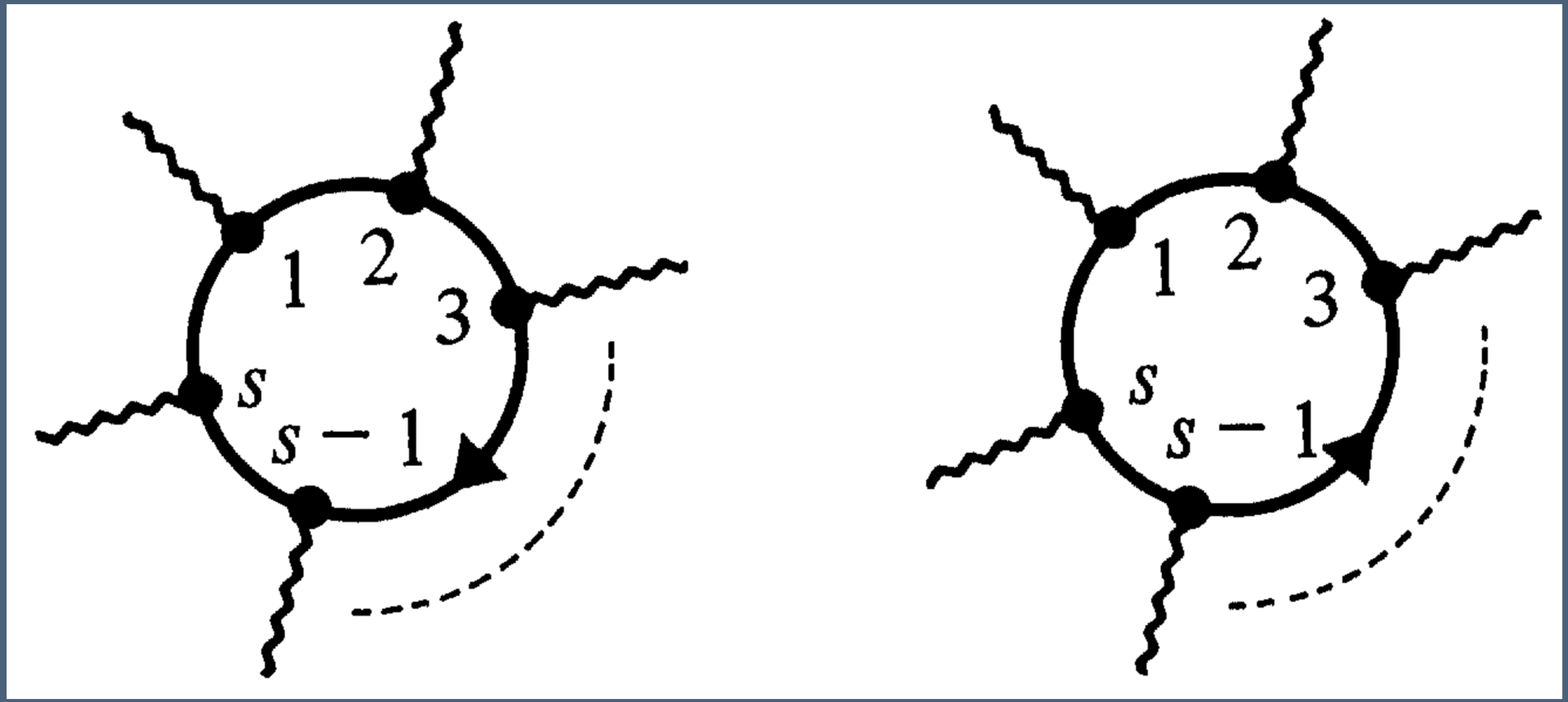
Furry's Theorem

Sketch of the proof in QED

- Consider all the diagrams with one fermion loop and an odd number of vertices

- If we insert CC^{-1} in the amplitude for one diagram, between propagators and consider the transformation of the vertex and the propagators under $\hat{C}$, then we see that, up to $(-1)^s$, the contribution of the two diagrams is the same

- Hence, for odd s, the contributions cancel



C. Itzykson and J.-B. Zuber, Quantum Filed Theory

Sketch of the computation of the vertex

"Step-by-step" instructions

- Following Feynman's rules, we write the amplitude in position space. We note that the product of Schwinger phases factor out of the loop's momentum integration
- Since the external bosons are neutral, we Fourier transform to momentum space and integrate over configuration space. This will lead to the conservation of 4-momentum
- Then we integrate over the loop momenta. All of this integrals can be converted into Gaussian integrals
- After lots and lots of Gaussian integrals and algebra we arrive at the desired expression for the vertex
- It remains to integrate over the Schwinger proper times, but this will be numerical work