Prompt photons from gluon fusion/splitting induced by magnetic fields in heavy-ion collisions

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AA, J.D. Castaño-Yepes, I. Domínguez, J. Salinas, M.E. Tejeda-Yeomans, arXiv:1904.02938

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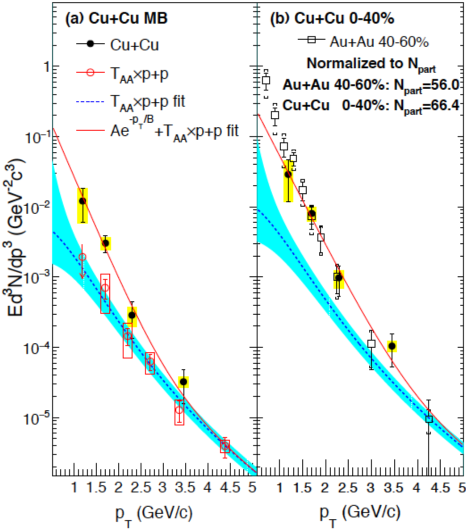
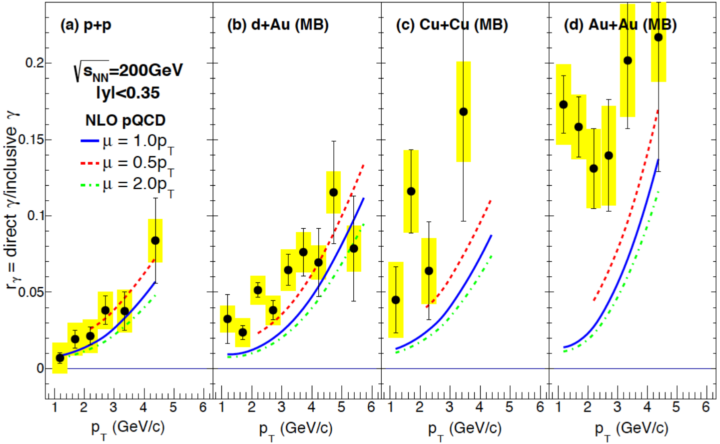
Overview

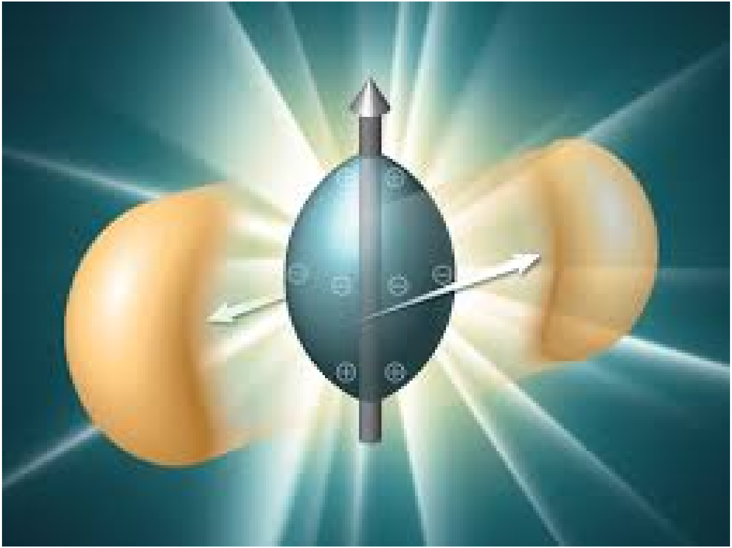
PHENIX, PRC **98**, 054902 (2018)



PHENIX, PRC **98**, 054902 (2018)



Magnetic field generated in peripheral HICs



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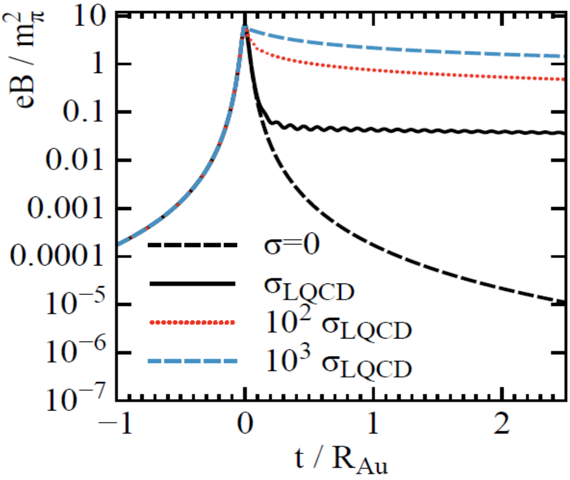
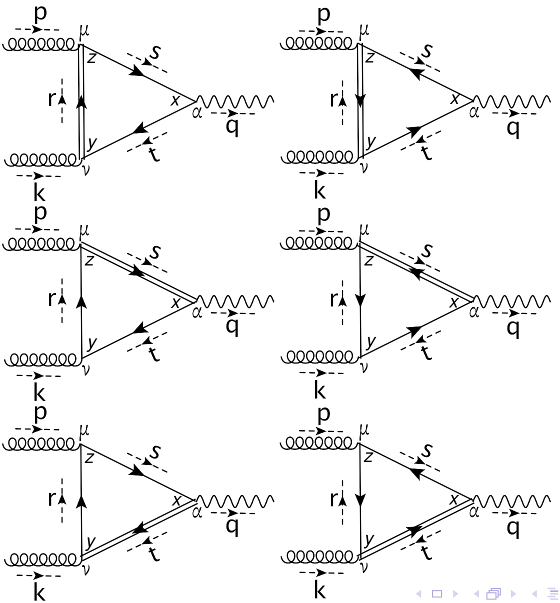
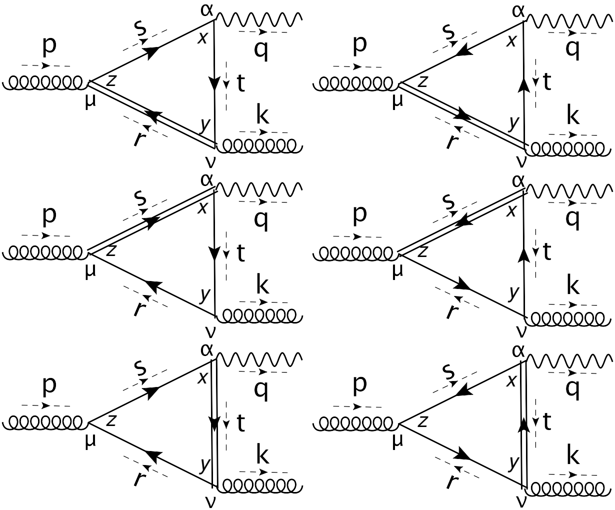


Gluon fusion



Gluon splitting



Gluon fusion Matrix Element

$$
\begin{aligned}
\widetilde{\mathcal{M}}_{gg\to\gamma} &= -\int d^4x d^4y d^4z \int \frac{d^4r}{(2\pi)^4}\frac{d^4s}{(2\pi)^4}\frac{d^4t}{(2\pi)^4} \\
&\times \; e^{-it\cdot(y-x)}e^{-is\cdot(x-z)}e^{-ir\cdot(z-y)}e^{-ip\cdot z}e^{-ik\cdot y}e^{iq\cdot x} \\
&\times \; \Big\{ \mathrm{Tr}\left[ieq_f\gamma_\alpha iS(s)ig\gamma_\mu t^c iS(r)ig\gamma_\nu t^d iS(t)\right] \\
&+ \; \mathrm{Tr}\left[ieq_f\gamma_\alpha iS(t)ig\gamma_\nu t^d iS(r)ig\gamma_\mu t^c iS(s)\right]\Big\} \\
&\times \; \Phi(x,y)\Phi(y,z)\Phi(z,x)\epsilon^\mu(\lambda_p)\epsilon^\nu(\lambda_k)\epsilon^\alpha(\lambda_q) + \mathrm{C.C.}
\end{aligned}
$$

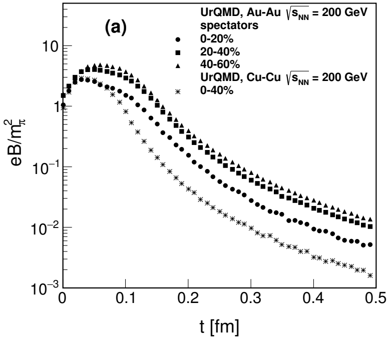
Quark propagator in a magnetic field

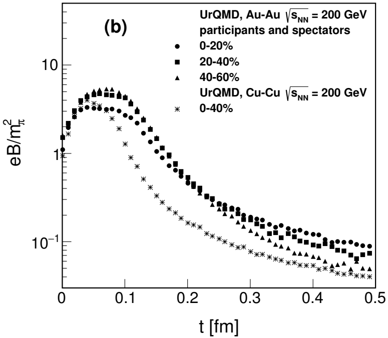
$$
\begin{aligned}
S(x,x') &= \Phi(x,x')\int \frac{d^4p}{(2\pi)^4} e^{-p\cdot(x-x')} S(p), \\
iS(p) &= \int_0^\infty \frac{d\tau}{\cos(|eq_fB|\tau)} e^{i\tau\left[p_\parallel^2 - p_\perp^2\frac{\tan(\tau)}{\tau} - m_f^2 + i\epsilon\right]} \\
&\times \left\{ \left[\cos(\tau) + \gamma_1\gamma_2\sin(\tau)\right](m_f + \not{p}_\parallel) - \frac{\not{p}}{\cos(\tau)} \right\}, \\
\Phi(x,x') &= e^{ieq_f\int_{x'}^{x} d\xi^\mu\left[A_\mu + \frac{1}{2}F_{\mu\nu}(\xi - x')^\nu\right]}.
\end{aligned}
$$

LLL and 1LL massless quarks

$$
\begin{aligned}
iS^{(0)}(p) &= i\frac{e^{-p_\perp^2/|eq_fB|}}{p_\parallel^2}\not{p}_\parallel\mathcal{O}^- \\
iS^{(1)}(p) &= -2i\frac{e^{-p_\perp^2/|eq_fB|}}{p_\parallel^2 - 2\,|eq_fB|} \\
&\times \left[2\not{p}_\parallel\mathcal{O}^-\left(1-\frac{2p_\perp^2}{|eq_fB|}\right) - 2\not{p}_\parallel\mathcal{O}^+ + 4\not{p}_\perp\right] \\
\mathcal{O}^{(\pm)} &= \left[1 \pm i\gamma^1\gamma^2\text{sign}(eq_fB)\right]/2
\end{aligned}
$$

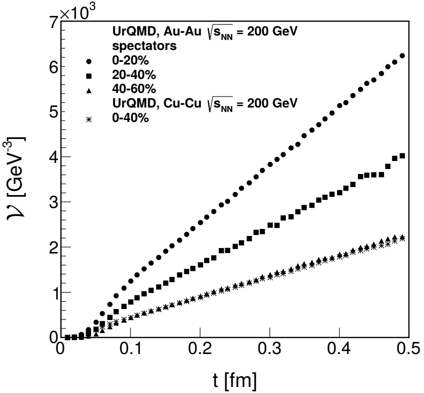
Field strength as a function of time: Lienard-Wiechert potential UrQMD





$$eB(\mathbf{x}, t) = \alpha_{em} \sum_j \frac{(1 - v_j^2)\ \mathbf{v}_j \times \mathbf{R}_j}{R_j^3 \left[1 - \frac{(\mathbf{v}_i \times \mathbf{R}_j)^2}{R_j^2}\right]^{3/2}}$$

UrQMD interaction volume as a function of time



$$\mathcal{V}(t) = 2t\pi r_A^2 \left(\frac{N_{\text{part}}}{2N}\right)^{2/3}$$

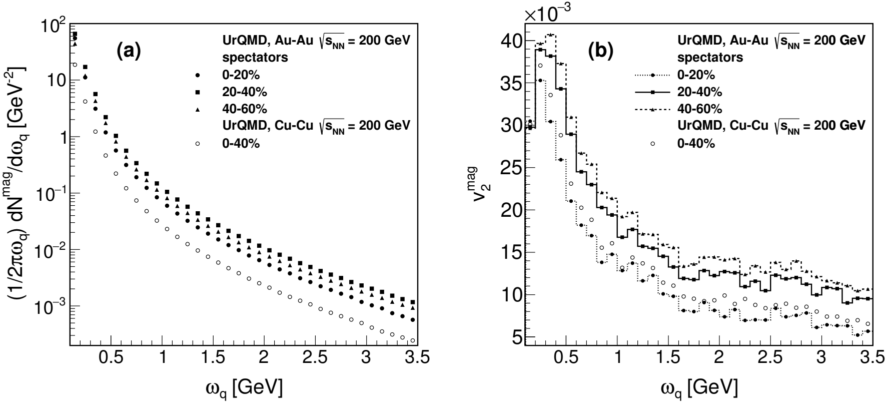
Matrix element squared

$$\overline{\sum_{\text{c,p,f}}} |\widetilde{\mathcal{M}}|^2 = \mathcal{V}\Delta\tau(2\pi)^4 \overline{\sum_{\text{c,p,f}}} \Bigg[\delta^{(4)}\left(q-k-p\right)|\mathcal{M}_{gg\to\gamma}|^2 + \delta^{(4)}\left(q+k-p\right)|\mathcal{M}_{g\to g\gamma}|^2 \Bigg],$$

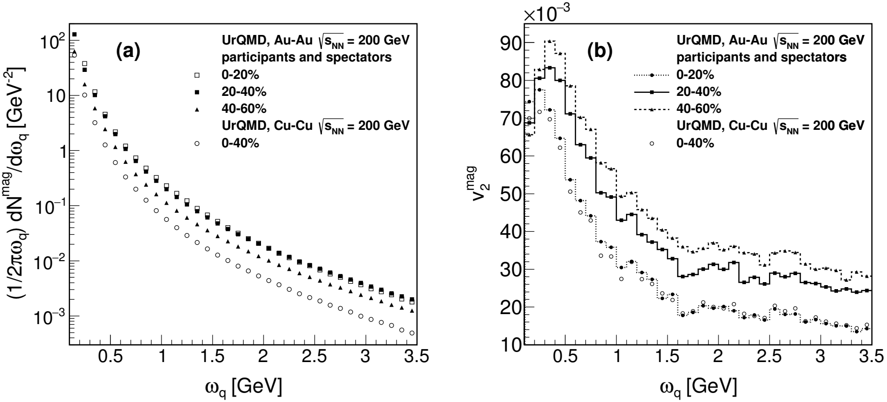
where

$$\overline{\sum_{\text{c,p,f}}} |\mathcal{M}_{gg\to\gamma}|^2 = \overline{\sum_{\text{c,p,f}}} |\mathcal{M}_{g\to g\gamma}|^2 = \frac{2\alpha_{\rm em}\alpha_s^2 q_\perp^2}{\pi\omega_q^2} \sum_f q_f^2 \left(2\omega_p^2+\omega_k^2+\omega_p\omega_k\right) \times \exp\left\{-\frac{q_\perp^2}{\omega_q^2}\left(\omega_p^2+\omega_k^2+\omega_p\omega_k\right)\right\}$$

Photon yield and v_2 from magnetic fields (spectators)

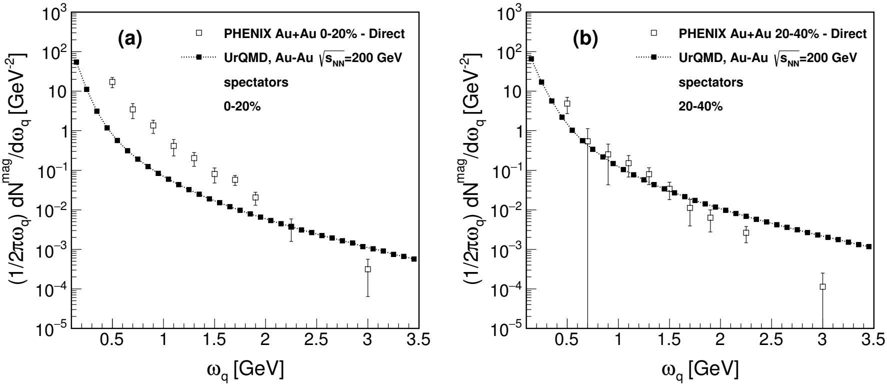


Photon yield and v_2 from magnetic fields (spectators & participants)



Excess photon yield compared to PHENIX

- Direct photons from Paquet *et. al*, Phys. Rev. C **93**, 044906 (2016).



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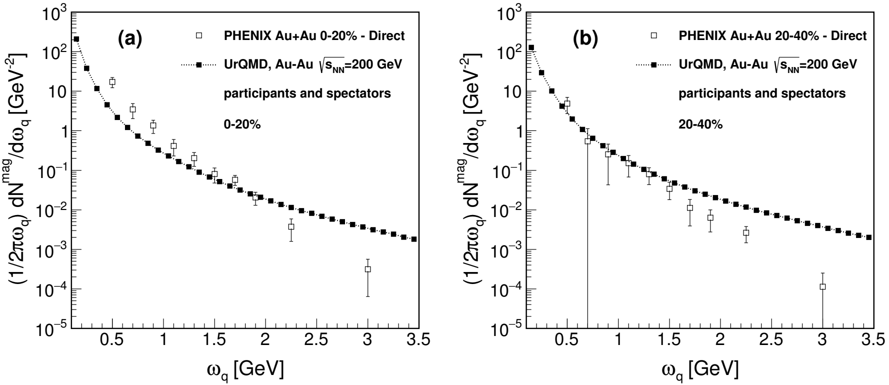
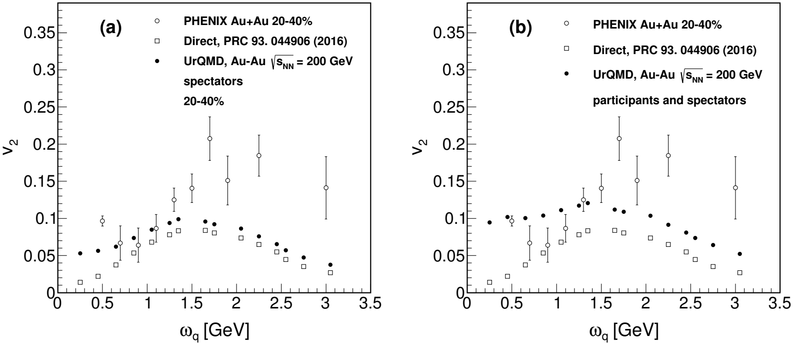


Weighed v_2 average (prompt and magnetic)



$$v_2(\omega_q) = \frac{\sum_{i=1}^{m} \left[\frac{dN}{d\omega_q}\right]_i [v_2^{\text{mag}}(\omega_q)]_i + \frac{dN^{\text{direct}}}{d\omega_q}(\omega_q)\; v_2^{\text{direct}}(\omega_q)}{\sum_{i=1}^{m} \left[\frac{dN}{d\omega_q}\right]_i + \frac{dN^{\text{direct}}}{d\omega_q}(\omega_q)},$$

Conclusions

- Intense magnetic field effects during the very early stages of a Relativistic Heavy-Ion Collision.
- High gluon occupation number during early stages together with the magnetic field opens up gluon fusion/splitting channel for photon production.
- We used UrQMD to compute the time evolution of the field intensity and volume reaction to include magnetic field effects in the strong field limit.
- Photon yield and elliptic flow excess better described with magnetic field effects at low energy for semi-central Au + Au and Cu + Cu collisions.