Prompt photon production from a magnetized glasma

Jorge David Castaño Yepes

In collaboration with:

A. Ayala, I. Domínguez, L. Hernández, S. Hernández, J. Salinas & M.E. Tejeda-Yeomans

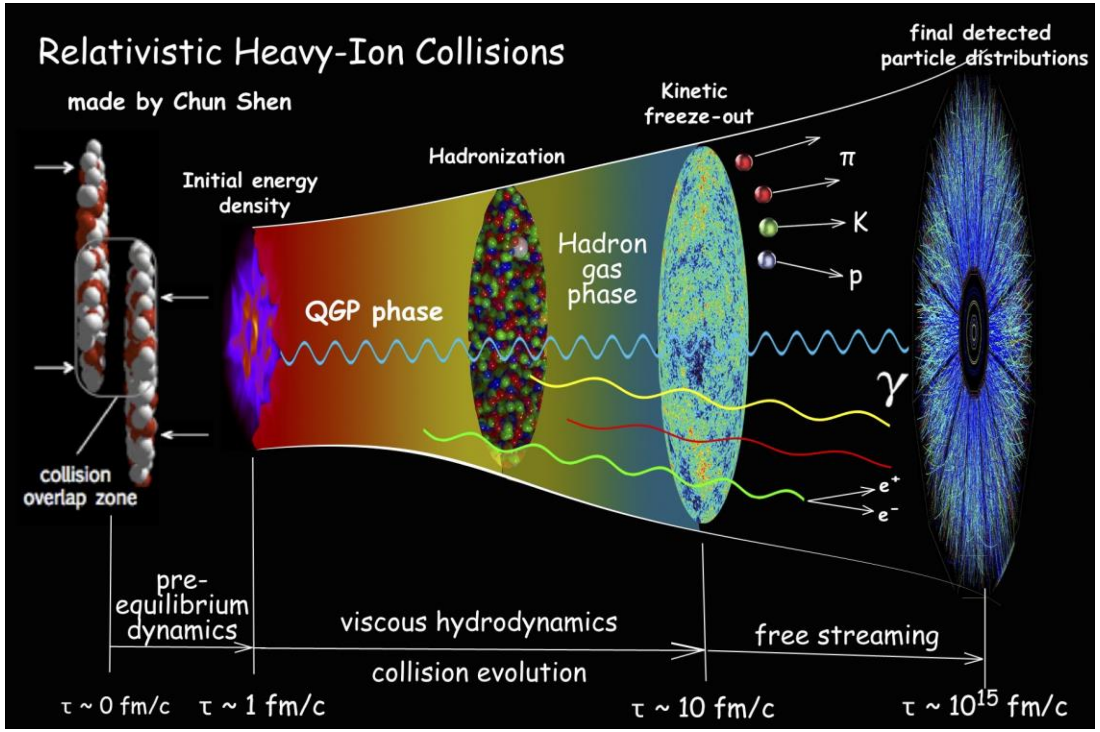
MexNICA Collaboration Winter Meeting
2020

Outline

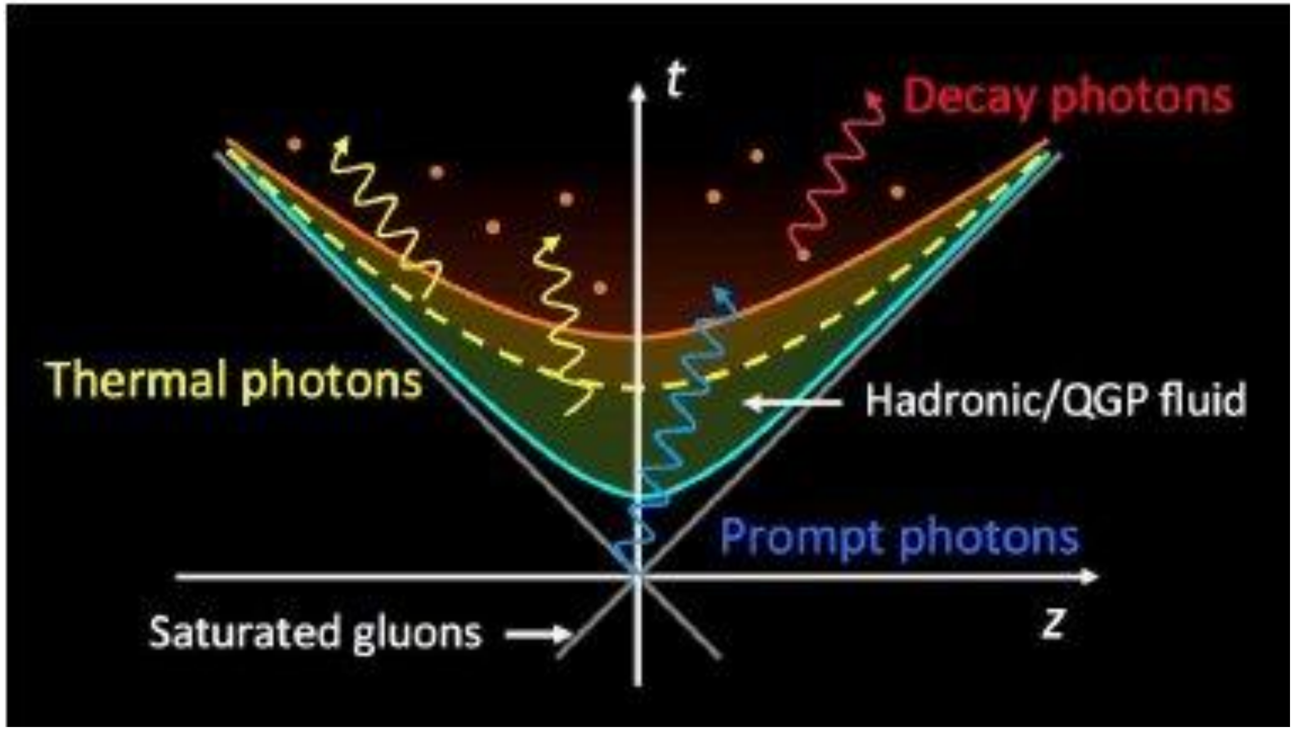
- Motivation (The Photon Puzzle).
- The Color Glass Condensate.
- Magnetic Fields in Heavy-Ion Collisions.
- Gluon Fusion and Splitting in a Magnetized Glasma.
- Results.
- Conclusions.

Motivation

Photons in Heavy-Ion Collisions



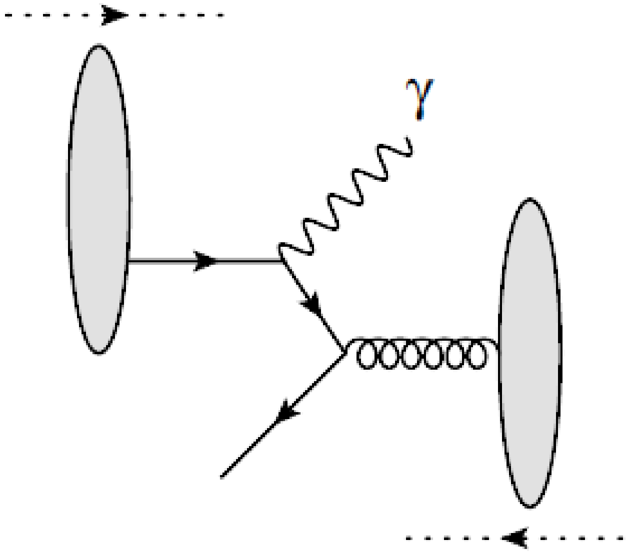
[https://u.osu.edu/vishnu/category/visualization/]



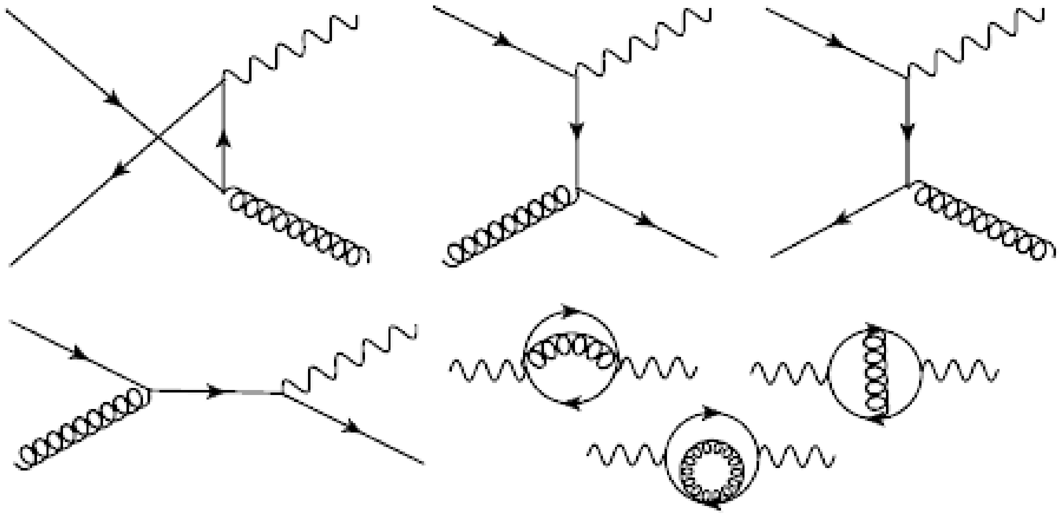
[A. Monnai, J. Phys. Conf. Ser. 612 (2015) 1, 012026]

Motivation

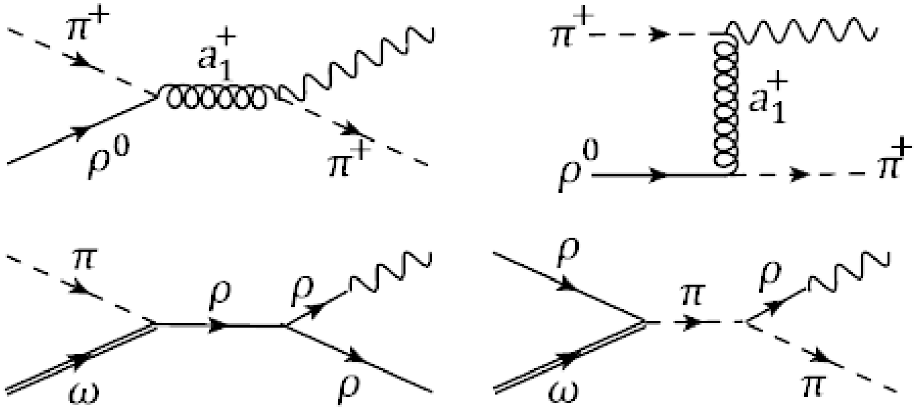
Prompt



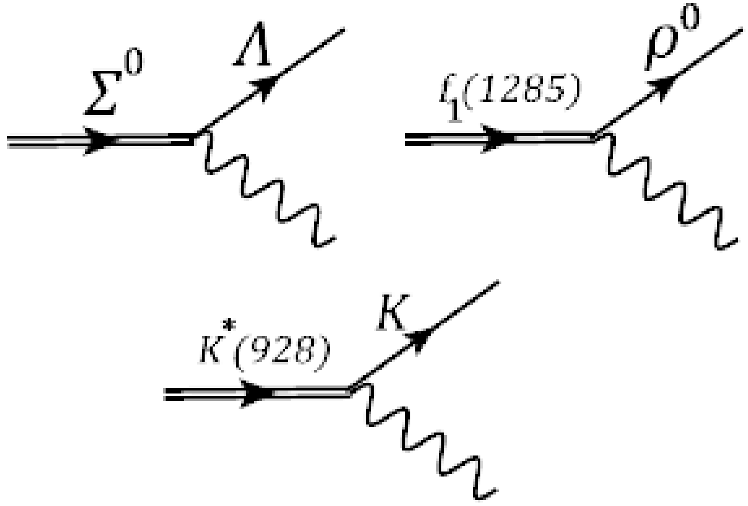
Thermal from QGP



Thermal from Mesons

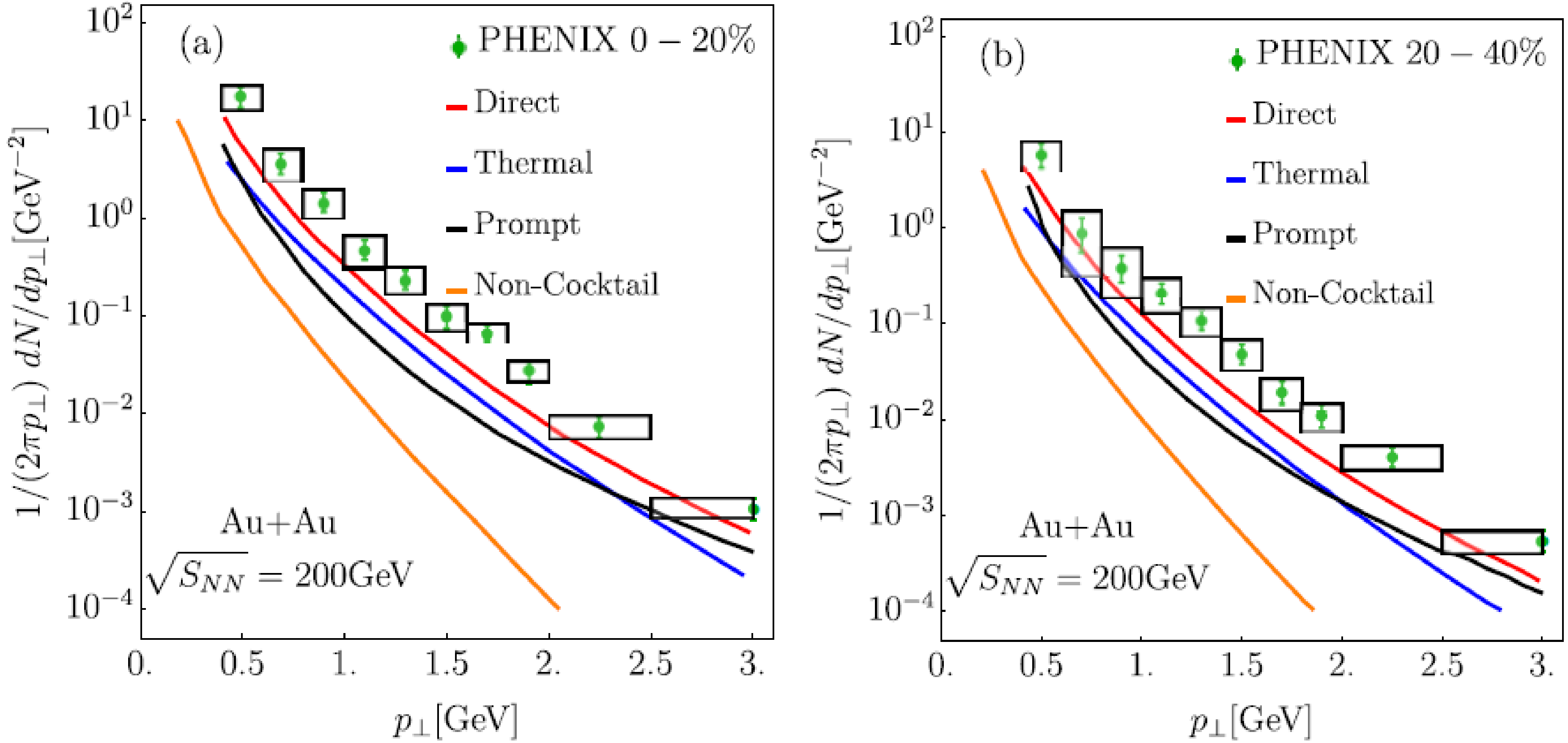


Non Cocktail



Motivation

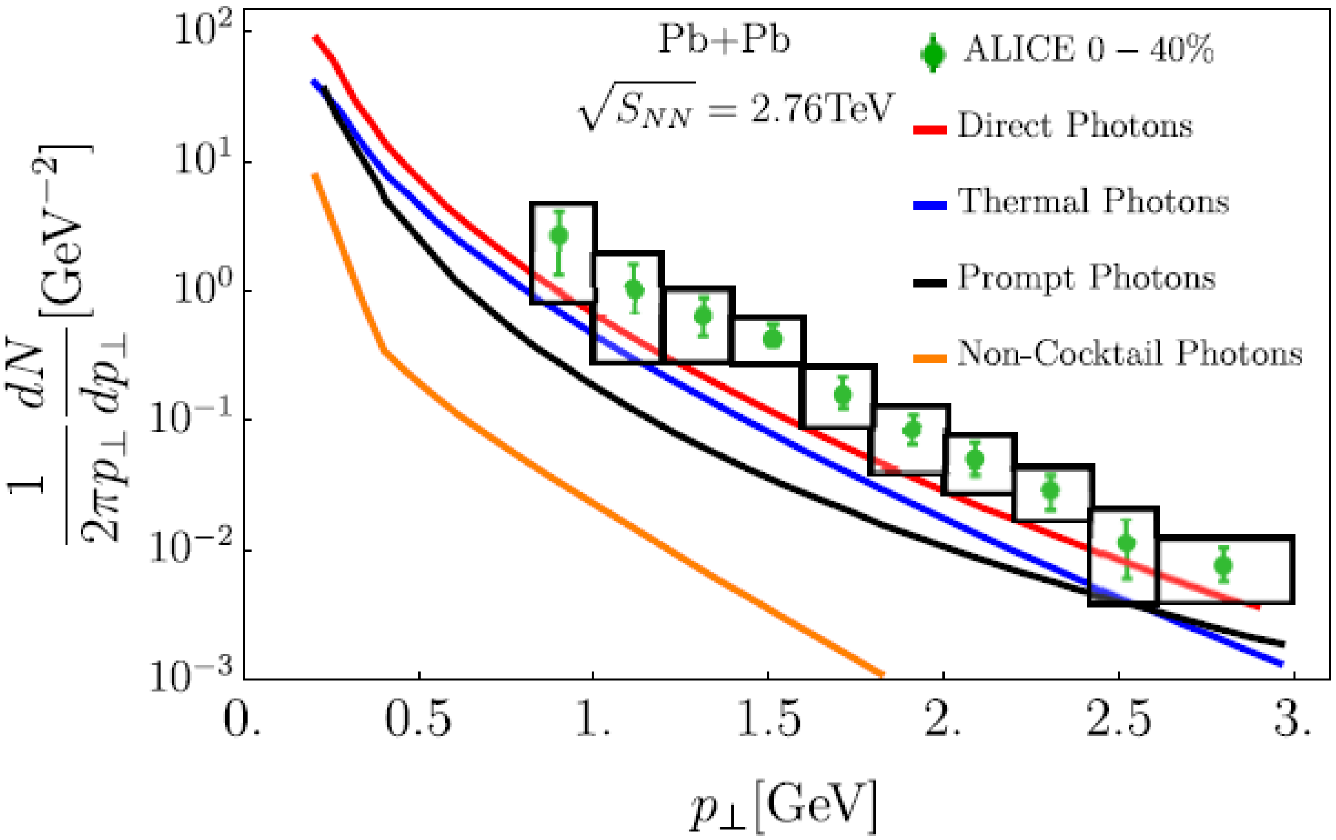
Model vs. Experiment: The Photon Puzzle



[PHENIX collaboration, PRC 91, 064904 (2016)]
[J.F. Paquet et al., PRC 93, 044906 (2016)]

Motivation

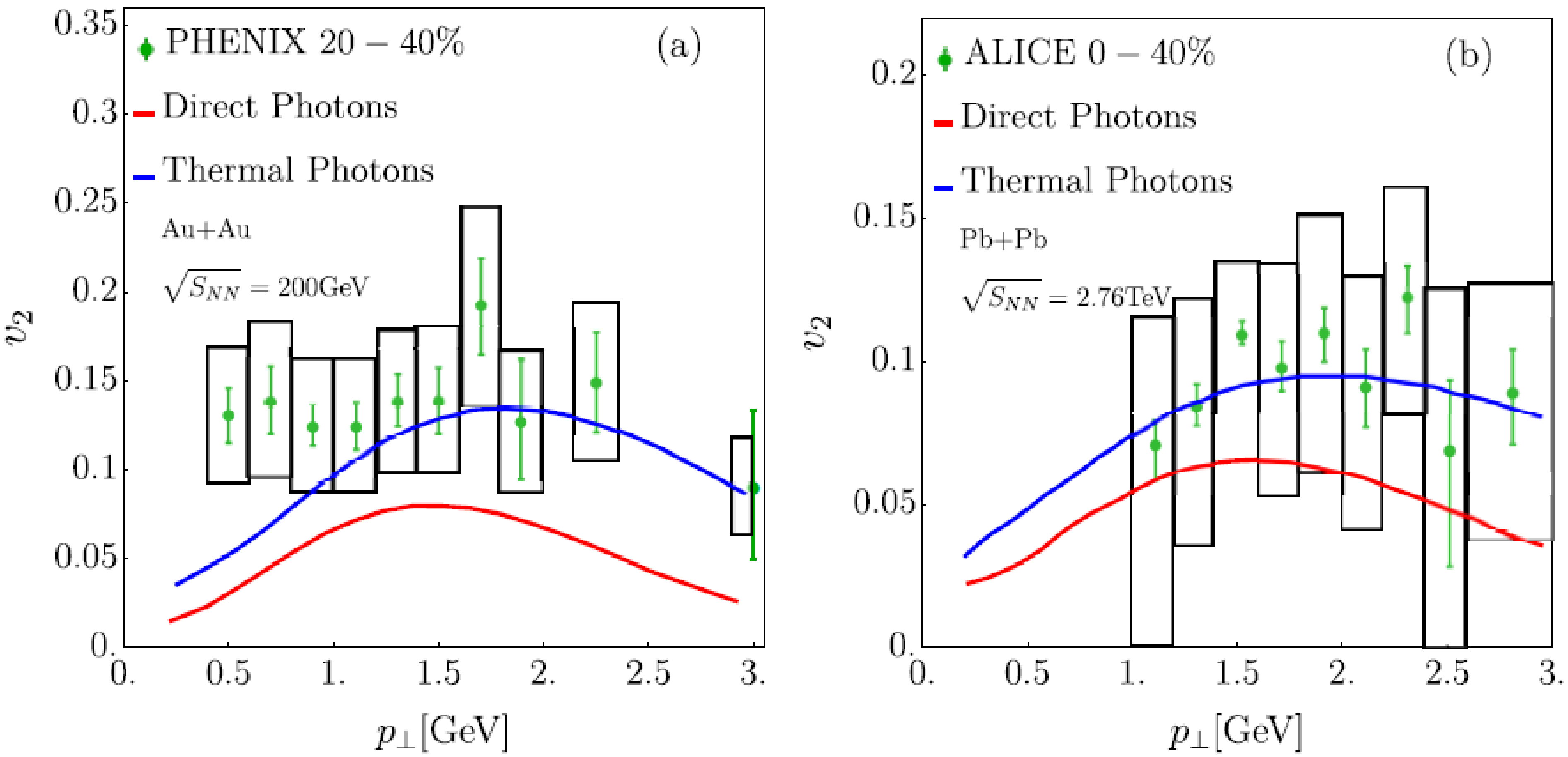
Model vs. Experiment: The Photon Puzzle



[ALICE collaboration, Nucl. Phys. A, 967, 696 (2017)]
[J.F. Paquet et al., PRC 93, 044906 (2016)]

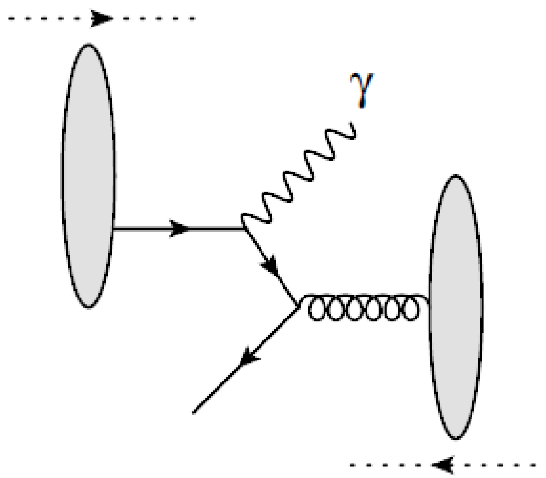
Motivation

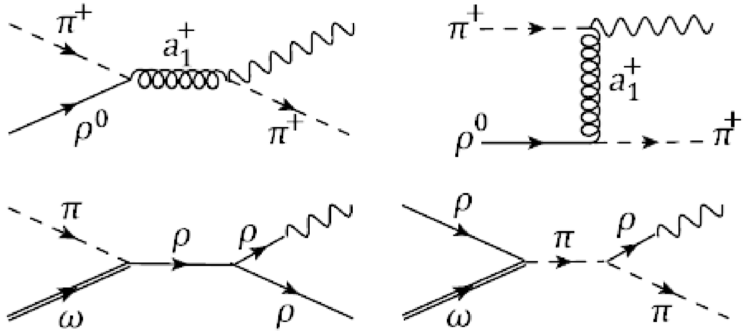
Model vs. Experiment: The Photon Puzzle

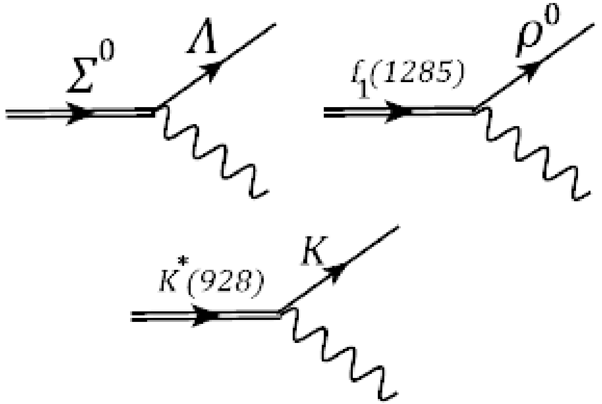


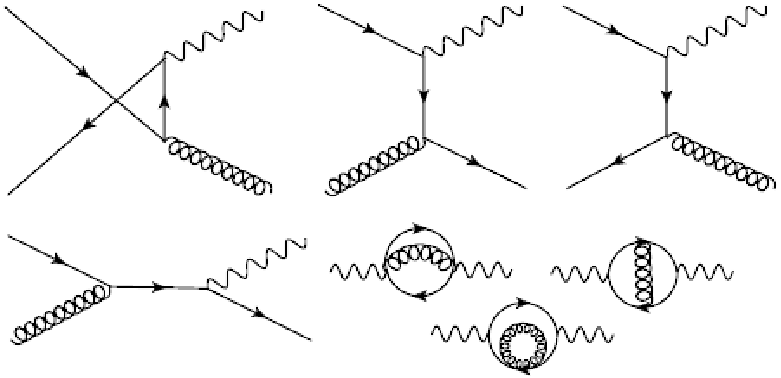
[PHENIX collaboration, Nucl. Phys. A 931, 1189 (2014)], [ALICE collaboration, Nucl. Phys. A, 967, 696 (2017)]
[J.F. Paquet et al., PRC 93, 044906 (2016)]

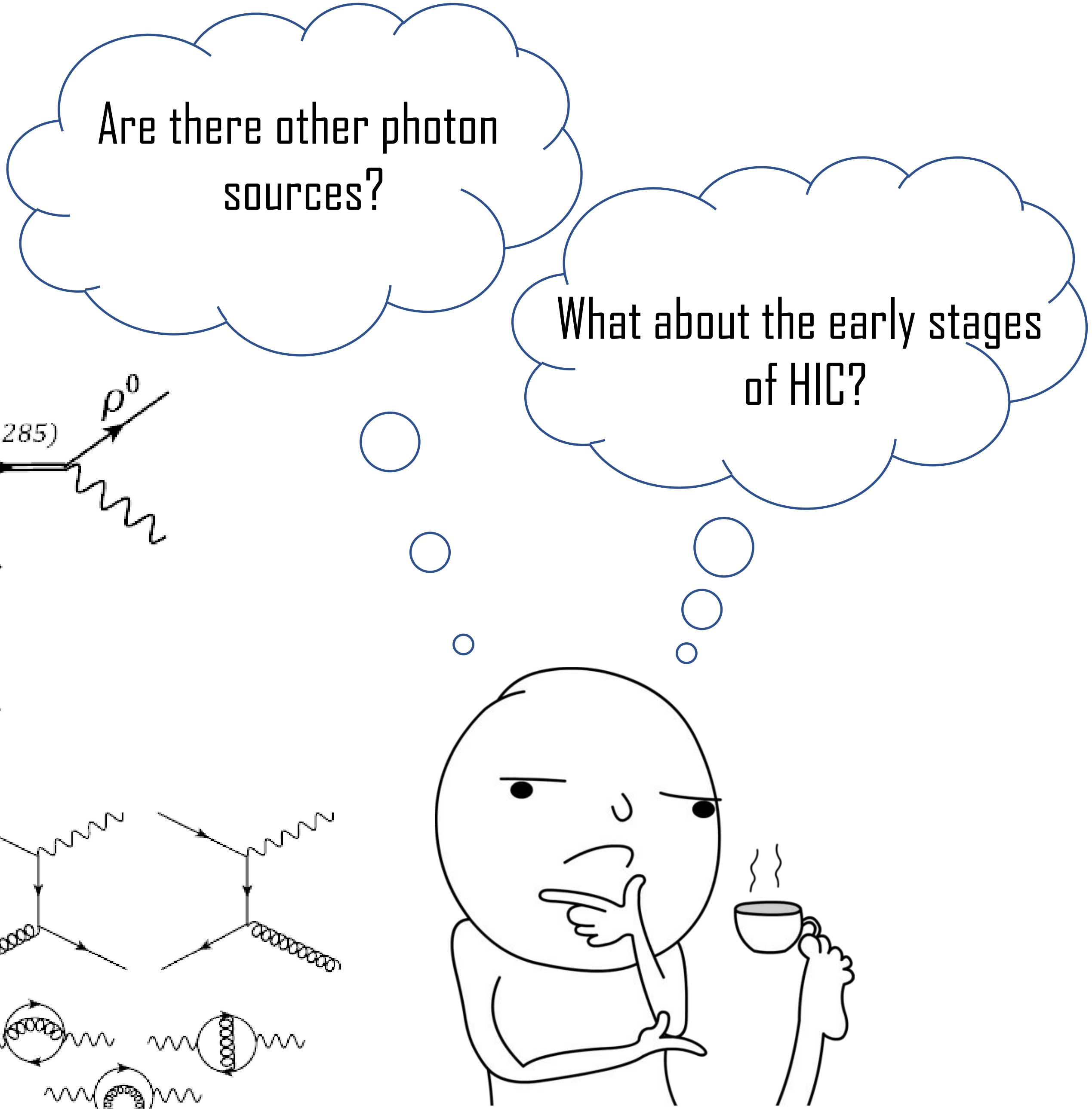
Motivation


γ

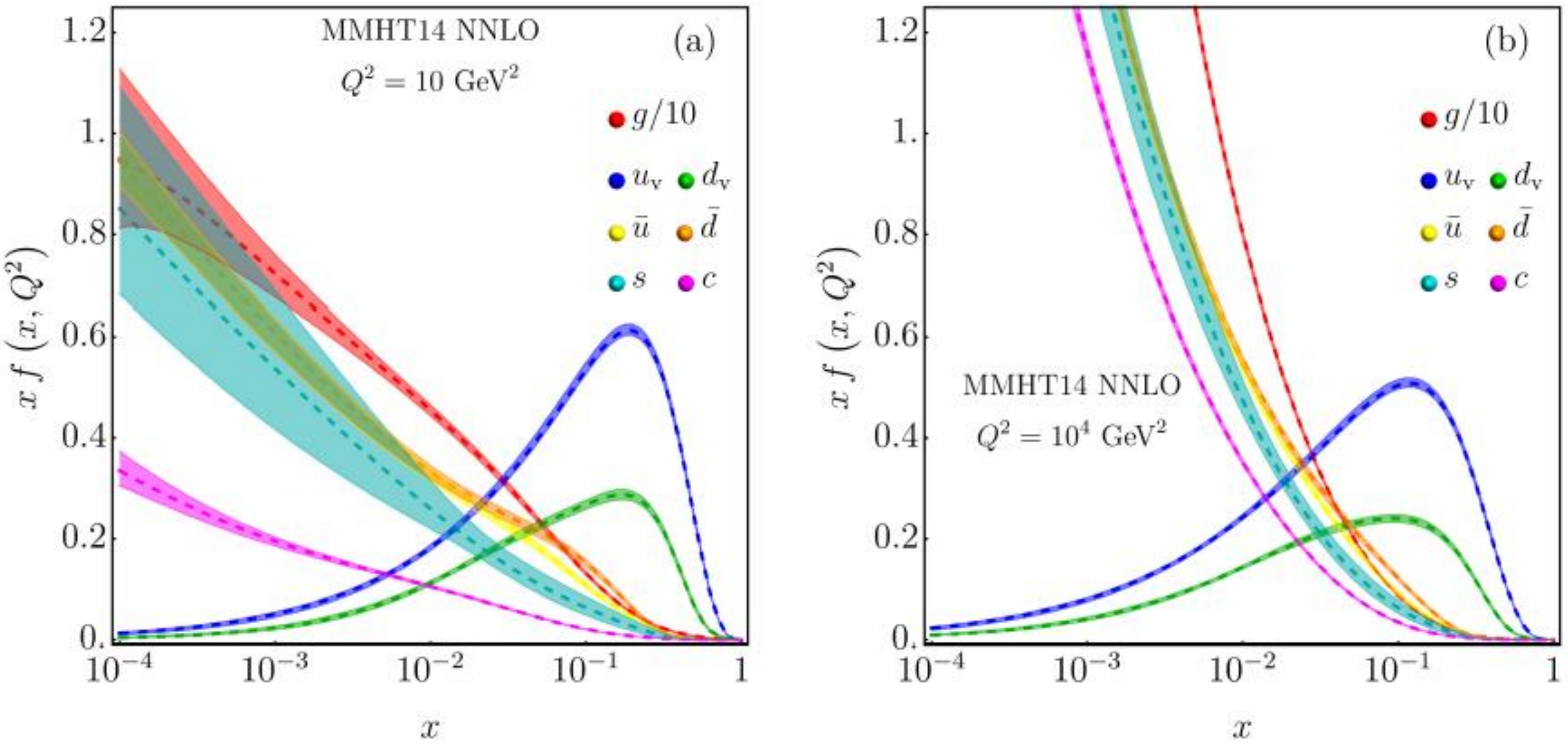

π+
a1+
ρ0
π+
π+
a1+
ρ0
π+
π
ρ
ρ
ω
ρ
ρ
π
ρ
ω
π


Σ0
Λ
f1(1285)
ρ0
K*(928)
K



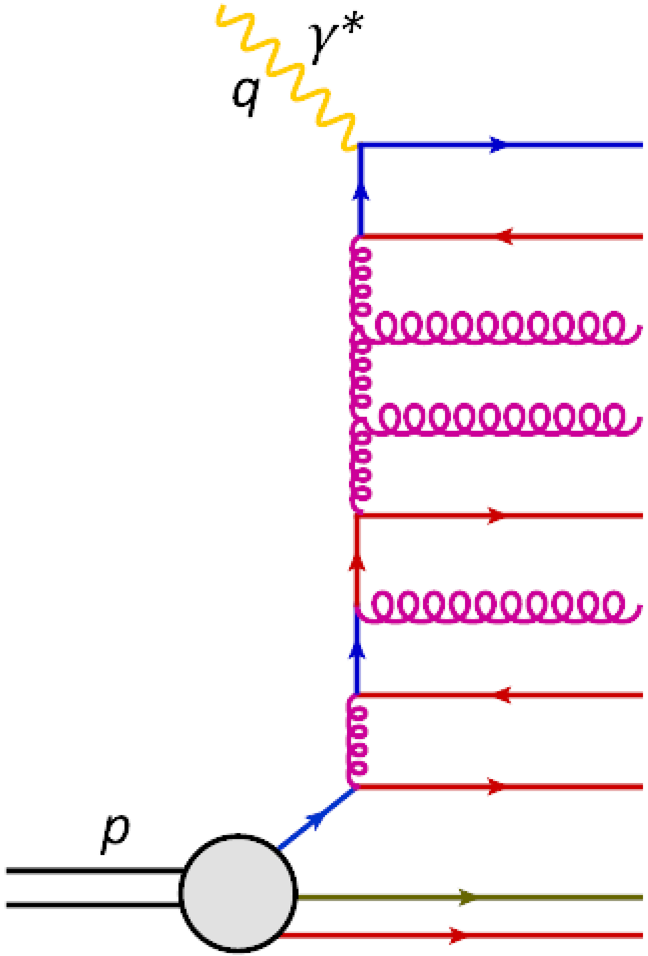

Are there other photon sources?
What about the early stages of HIC?

The Color Glass Condensate

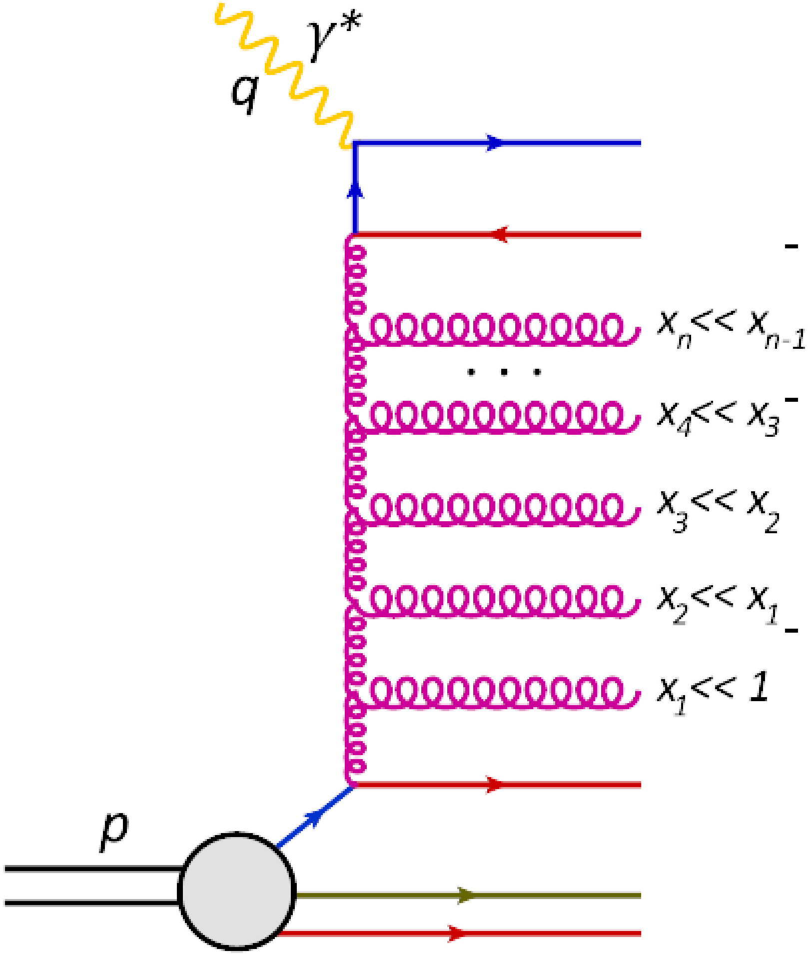


[L. A. Halard-Lang et al., Eur. Phys. J. C 75(5), 204 (2015)]

The Color Glass Condensate



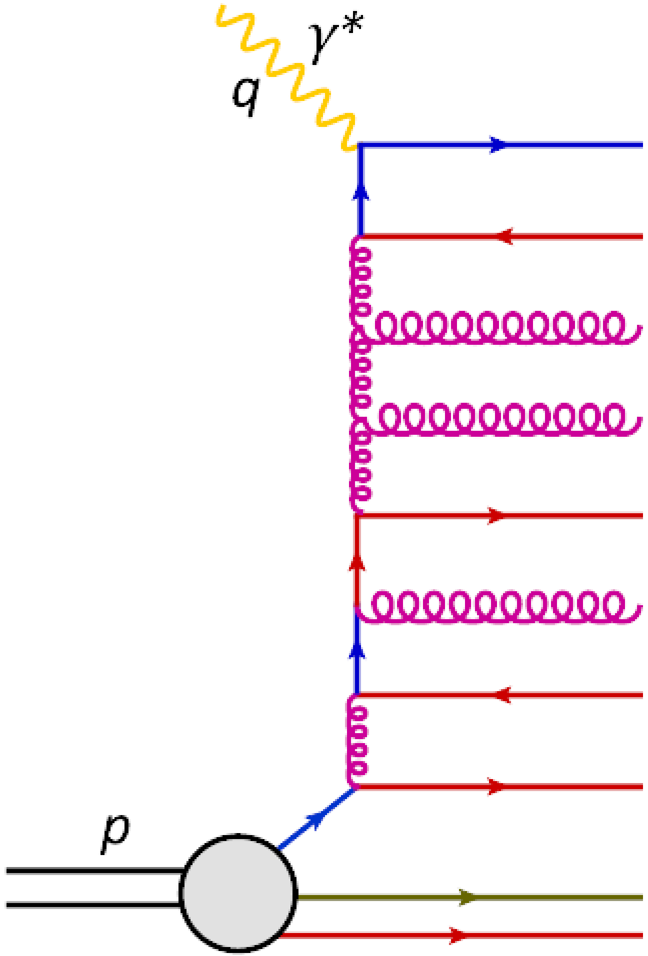
High Q^2 and fixed x:
Diluted system



High Q^2 and small x:
Dense system

- The system is dominated by gluons.
- Is a glass: for large x the color sources are static. For small x are slow gluons.
- The satured gluon occupation number adds its color charge coherently.

The Color Glass Condensate



High Q^2 and fixed x:
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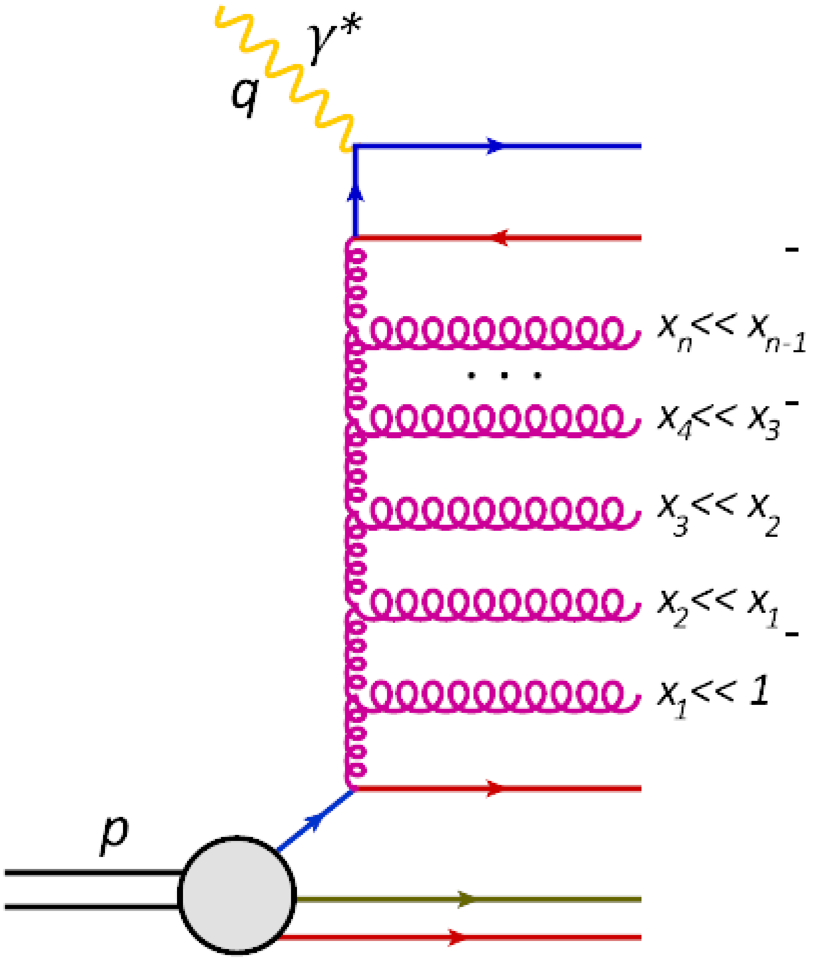

High Q^2 and small x:
Dense system

- The system is dominated by gluons.
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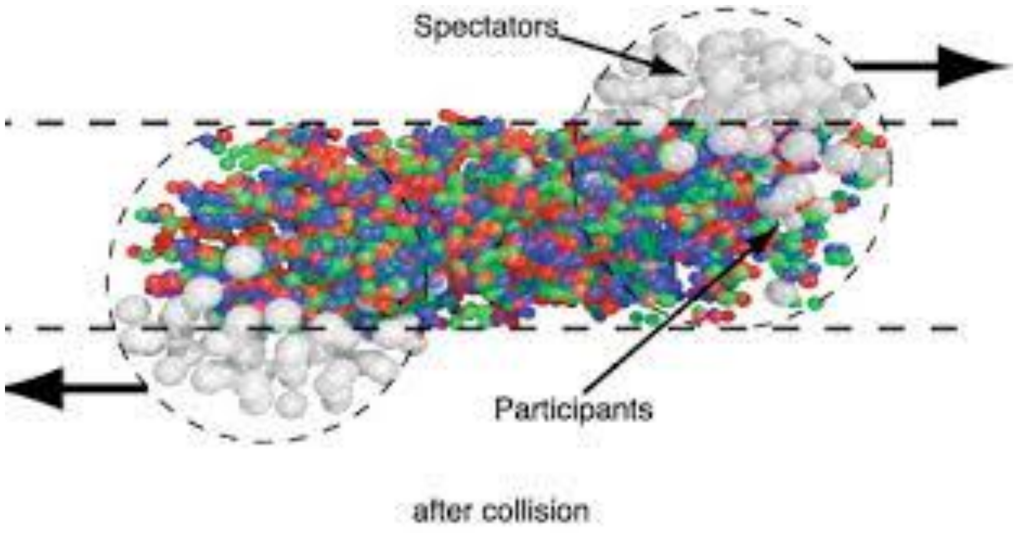
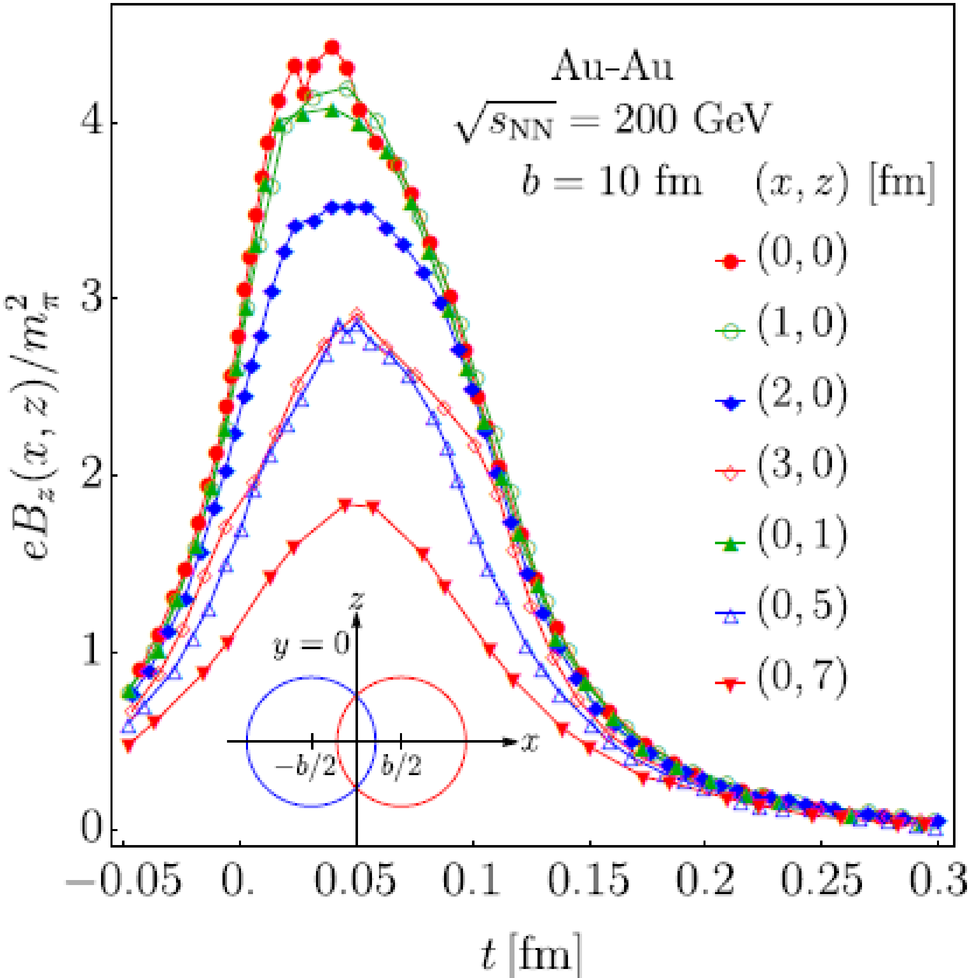
BUT GLUONS ARE NOT ALONE

Magnetic Fields in HIC



$$eB = \frac{\mathrm{sign}(e)\alpha[\mathbf{v} \times \mathbf{R}(t)]\,(1 - v^2/c^2)}{c\left[(\mathbf{R}(t)\cdot\mathbf{v}/c)^2 + R^2(t)\,(1 - v^2/c^2)\right]^{3/2}}$$

$m_\pi^2 \sim 10^{18}$Gauss



[V. Voronyuk, PRC 83, 054911 (2011)]

Gluon Fusion and Splitting in a Magnetized Glasma

PHYSICAL REVIEW D 96, 014023 (2017)

Prompt photon yield and elliptic flow from gluon fusion induced by magnetic fields in relativistic heavy-ion collisions

Alejandro Ayala,[1,2] Jorge David Castaño-Yepes,[1] C. A. Dominguez,[2] L. A. Hernández,[1] Saúl Hernández-Ortiz,[1] and María Elena Tejeda-Yeomans[3]

Eur. Phys. J. A (2020) 56:53
https://doi.org/10.1140/epja/s10050-020-00060-9

THE EUROPEAN PHYSICAL JOURNAL A

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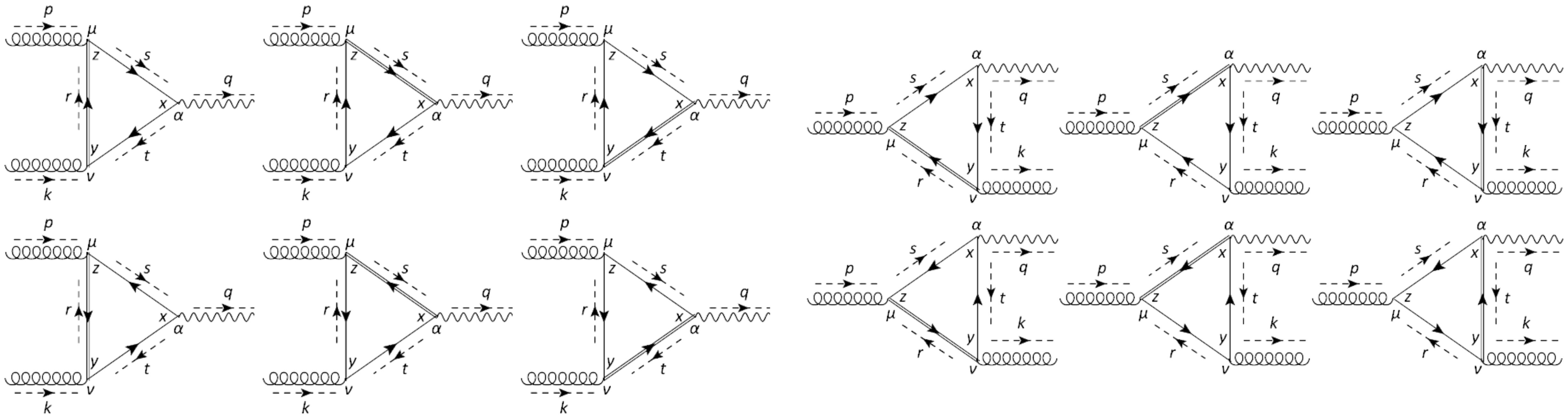
Regular Article -Theoretical Physics

Centrality dependence of photon yield and elliptic flow from gluon fusion and splitting induced by magnetic fields in relativistic heavy-ion collisions

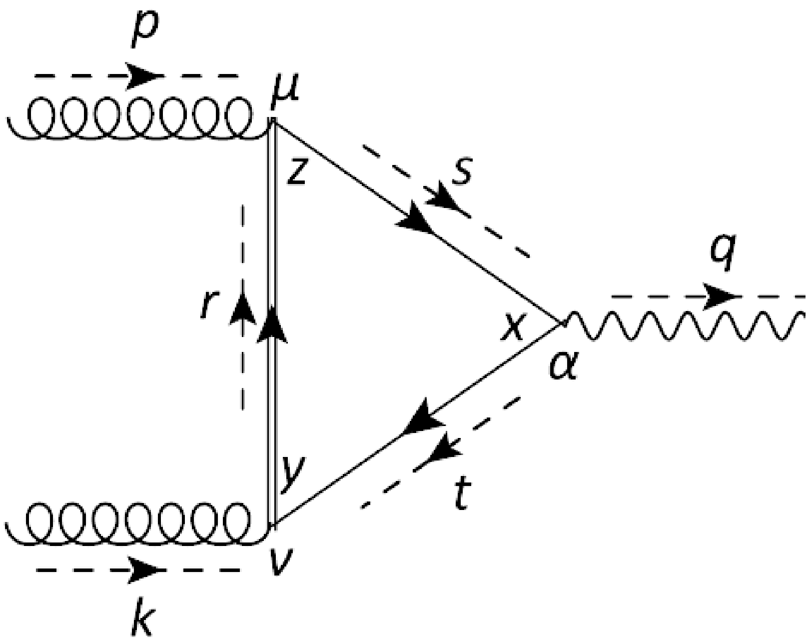
Alejandro Ayala[1,2], Jorge David Castaño-Yepes[1,a], Isabel Dominguez Jimenez[3], Jordi Salinas San Martín[1], María Elena Tejeda-Yeomans[4]

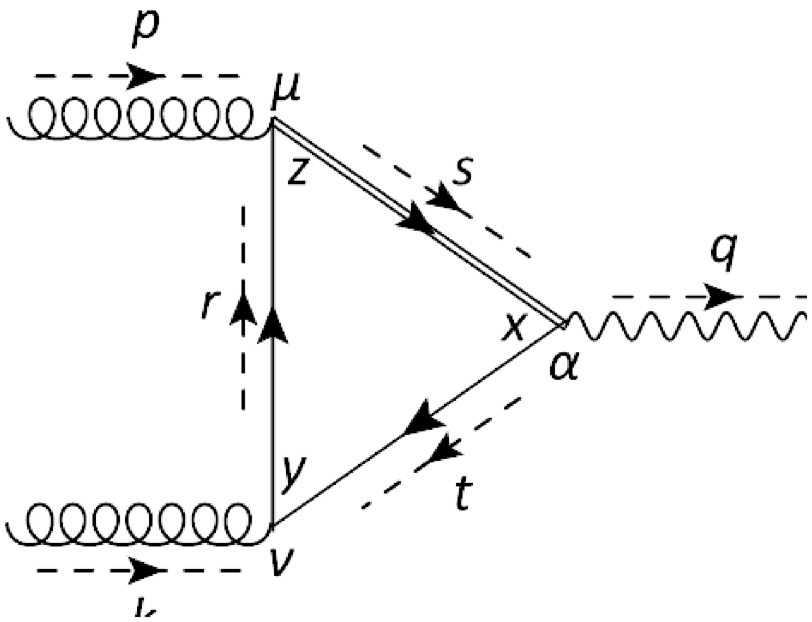
Gluon Fusion and Splitting in a Magnetized Glasma

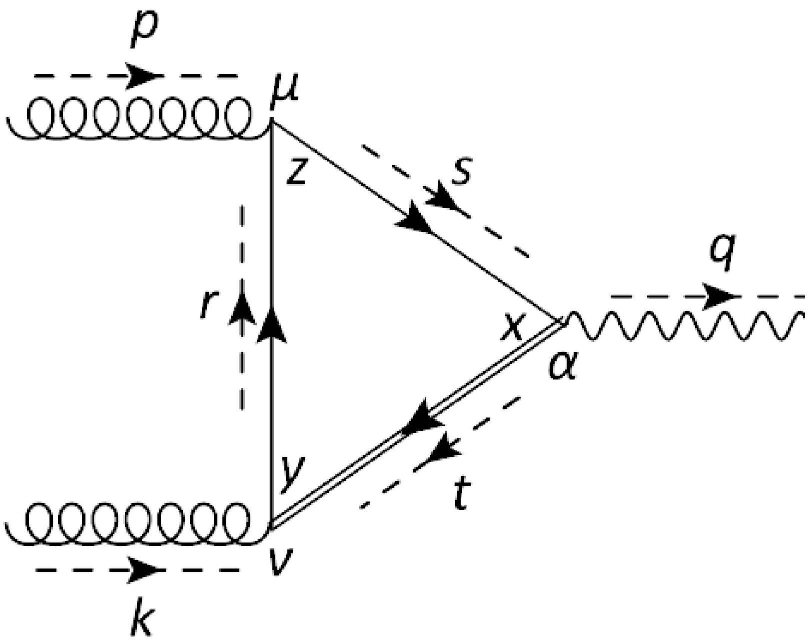


$$\mathcal{M}_{g\to g\gamma}(p,k,q) = \mathcal{M}_{gg\to\gamma}(p,-k,q)$$

Some details…







$$iS^{\mathrm{LLL}}(p) = i\frac{e^{-p_\perp^2/|q_f B|}}{p_\parallel^2}\not{p}_\parallel \mathcal{O}^-$$

$$iS^{\mathrm{1LL}}(p) = -2i\frac{e^{-p_\perp^2/|q_f B|}}{p_\parallel^2 - 2|q_f B|}\left[\left(1 - \frac{2p_\perp^2}{|q_f B|}\right)\not{p}_\parallel \mathcal{O}^- - \not{p}_\parallel \mathcal{O}^+ + 2\not{p}_\perp\right]$$

Some details…

$$
\begin{aligned}
\widetilde{\mathcal{M}} &= 8i(2\pi)^4\delta^{(4)}\left(q-k-p\right)\delta^{cd}|q_f|g^2 \\
&\times \int \frac{d^4r}{(2\pi)^4}\frac{d^4s}{(2\pi)^4}\frac{d^4t}{(2\pi)^4}\,\epsilon^{\mu}(\lambda_p)\epsilon^{\nu}(\lambda_k)\epsilon^{\alpha}(\lambda_q) \\
&\times \int d^4w\; d^4l\, e^{-il(r-t-k)}e^{-iw(r-s+p)}\exp\left\{-i\frac{|q_fB|}{2}\epsilon_{mj}w_m l_j\right\}\exp\left\{-\frac{r_\perp^2+s_\perp^2+t_\perp^2}{|q_fB|}\right\} \\
&\times \mathrm{Tr}\left\{\frac{\gamma_1\gamma_2\gamma_\alpha \not{t}_\perp\gamma_\nu \not{r}_\parallel\gamma_\mu^\parallel \not{s}_\parallel}{r_\parallel^2 s_\parallel^2\left(t_\parallel^2-2\,|q_fB|\right)}+\frac{\gamma_1\gamma_2\gamma_\mu \not{s}_\perp\gamma_\alpha \not{t}_\parallel\gamma_\nu^\parallel \not{r}_\parallel}{t_\parallel^2 r_\parallel^2\left(s_\parallel^2-2\,|q_fB|\right)}+\frac{\gamma_1\gamma_2\gamma_\nu \not{r}_\perp\gamma_\mu \not{s}_\parallel\gamma_\alpha^\parallel \not{t}_\parallel}{s_\parallel^2 t_\parallel^2\left(r_\parallel^2-2\,|q_fB|\right)}\right\}
\end{aligned}
$$

$$2|q_fB| \gg t_\parallel^2,\; s_\parallel^2,\; r_\parallel^2$$ (Low momentum approximation)

Some details...

$$
\begin{aligned}
\widetilde{\mathcal{M}} &= -i(2\pi)^4\delta^{(4)}(q-k-p)\frac{q_f g^2 \delta^{cd} e^{f(p_\perp,k_\perp)}}{32\pi(2\pi)^8}\epsilon_\mu(\lambda_p)\epsilon_\nu(\lambda_k)\epsilon_\alpha(\lambda_q) \\
&\times \left\{\left(g_\parallel^{\mu\alpha}-\frac{p_\parallel^\mu p_\parallel^\alpha}{p_\parallel^2}\right)h^\nu(a)-\left(g_\parallel^{\mu\nu}-\frac{p_\parallel^\mu p_\parallel^\nu}{p_\parallel^2}\right)h^\alpha(a)+\left(g_\parallel^{\mu\nu}-\frac{k_\parallel^\mu k_\parallel^\nu}{k_\parallel^2}\right)h^\alpha(b)\right. \\
&- \left.\left(g_\parallel^{\alpha\nu}-\frac{k_\parallel^\alpha k_\parallel^\nu}{k_\parallel^2}\right)h^\mu(b)+\left(g_\parallel^{\alpha\nu}-\frac{q_\parallel^\alpha q_\parallel^\nu}{q_\parallel^2}\right)h^\mu(c)-\left(g_\parallel^{\mu\alpha}-\frac{q_\parallel^\mu q_\parallel^\alpha}{q_\parallel^2}\right)h^\nu(c)\right\}
\end{aligned}
$$

$$
\sum_{\mathrm{pol},f}|\widetilde{\mathcal{M}}|^2=(2\pi)^4\delta^{(4)}(q-k-p)\mathcal{V}\Delta\tau\sum_{\mathrm{pol},f}|\mathcal{M}|^2
$$

$$
\sum_{\mathrm{pol},f}|\mathcal{M}|^2=\frac{2\alpha_{\mathrm{em}}\alpha_{\mathrm{s}}^2 q_\perp^2}{\pi\omega_q^2}\sum_f q_f^2\left(2\omega_p^2+\omega_k^2+\omega_p\omega_k\right)\exp\left\{-\frac{q_\perp^2}{|q_f B|\,\omega_q^2}\left(\omega_p^2+\omega_k^2+\omega_p\omega_k\right)\right\}
$$

Some details…

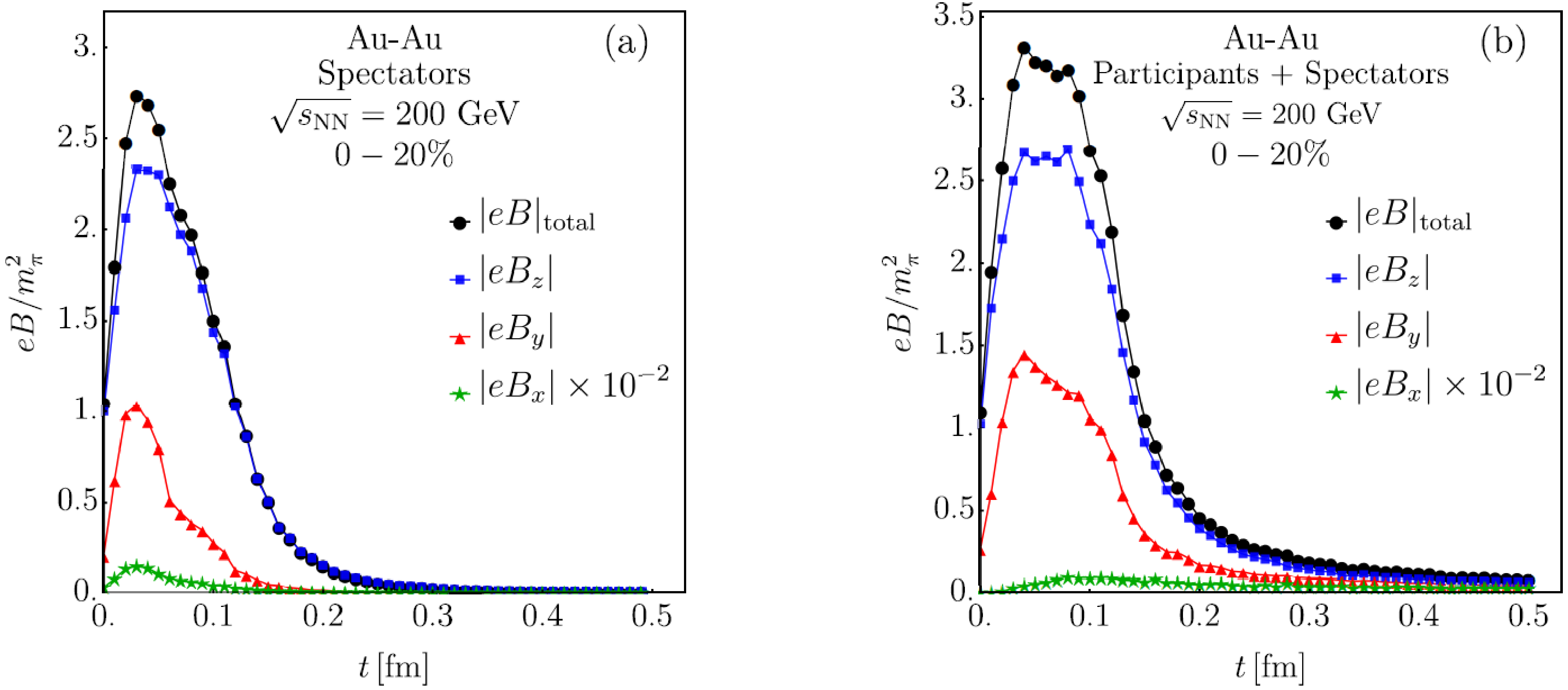
$$
\begin{aligned}
p^\mu &= \omega_p(1,\hat{p}) = (\omega_p/\omega_q)\, q^\mu , \\
k^\mu &= \omega_k(1,\hat{k}) = (\omega_k/\omega_q)\, q^\mu
\end{aligned}
$$

$$
\omega_q \frac{dN^{\mathrm{mag}}}{d^3q} = \frac{\chi \mathcal{V} \tau_s}{2(2\pi)^3} \int \frac{d^3p}{(2\pi)^3 2\omega_p} \int \frac{d^3k}{(2\pi)^3 2\omega_k} n(\omega_p) n(\omega_k) (2\pi)^4 \delta^{(4)}\left(q-k-p\right) \sum_{\mathrm{pol},f} |\mathcal{M}|^2
$$

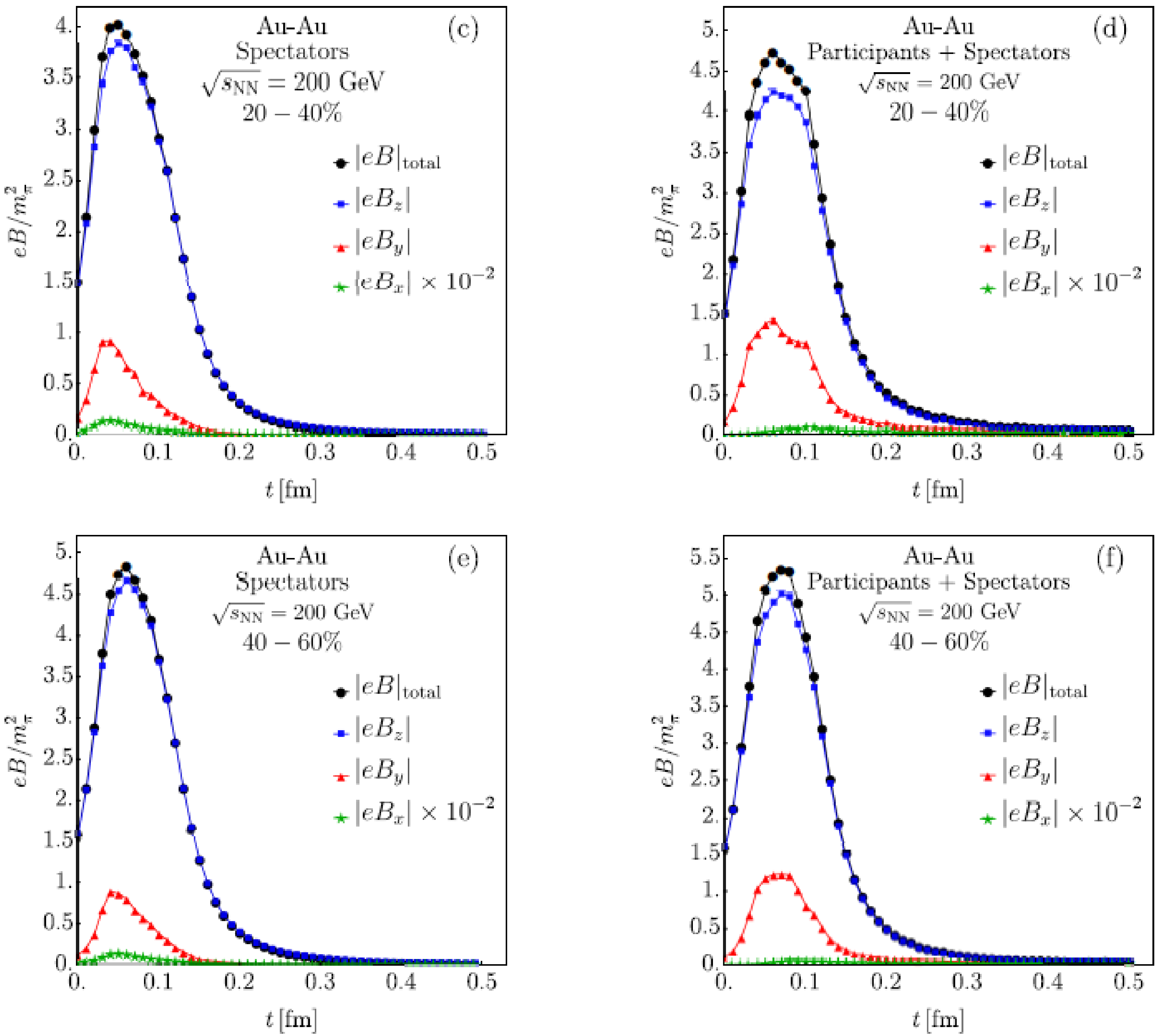
$$
\frac{dN^{\mathrm{mag}}}{d\varphi} = \frac{N^{\mathrm{mag}}}{2\pi}\left[1 + \sum_{n=1}^{\infty} 2 v_n(\omega_q)\cos(n\varphi)\right]
$$

$$
n(\omega) = \frac{\kappa}{e^{\omega/\Lambda_s} - 1}.
$$

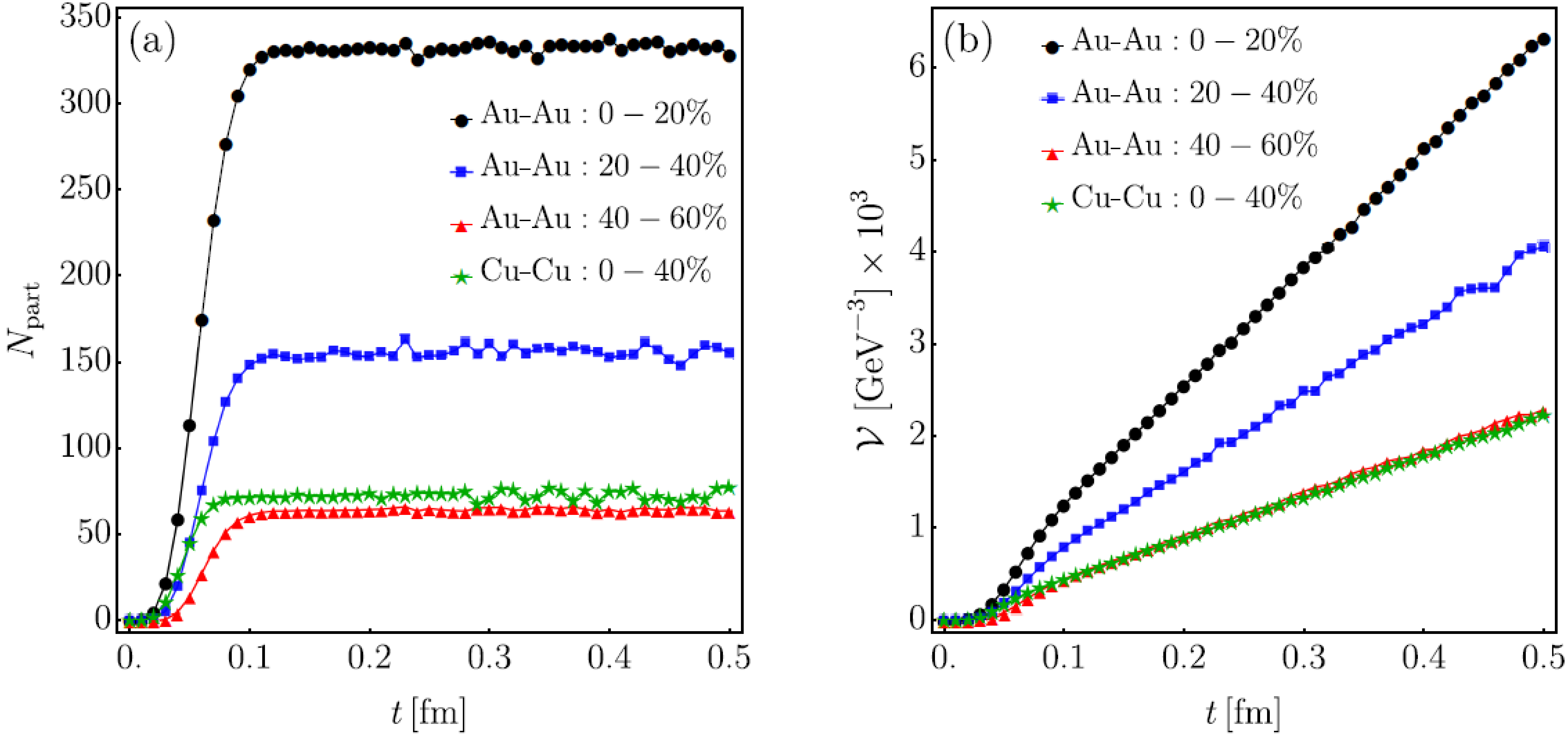
Results



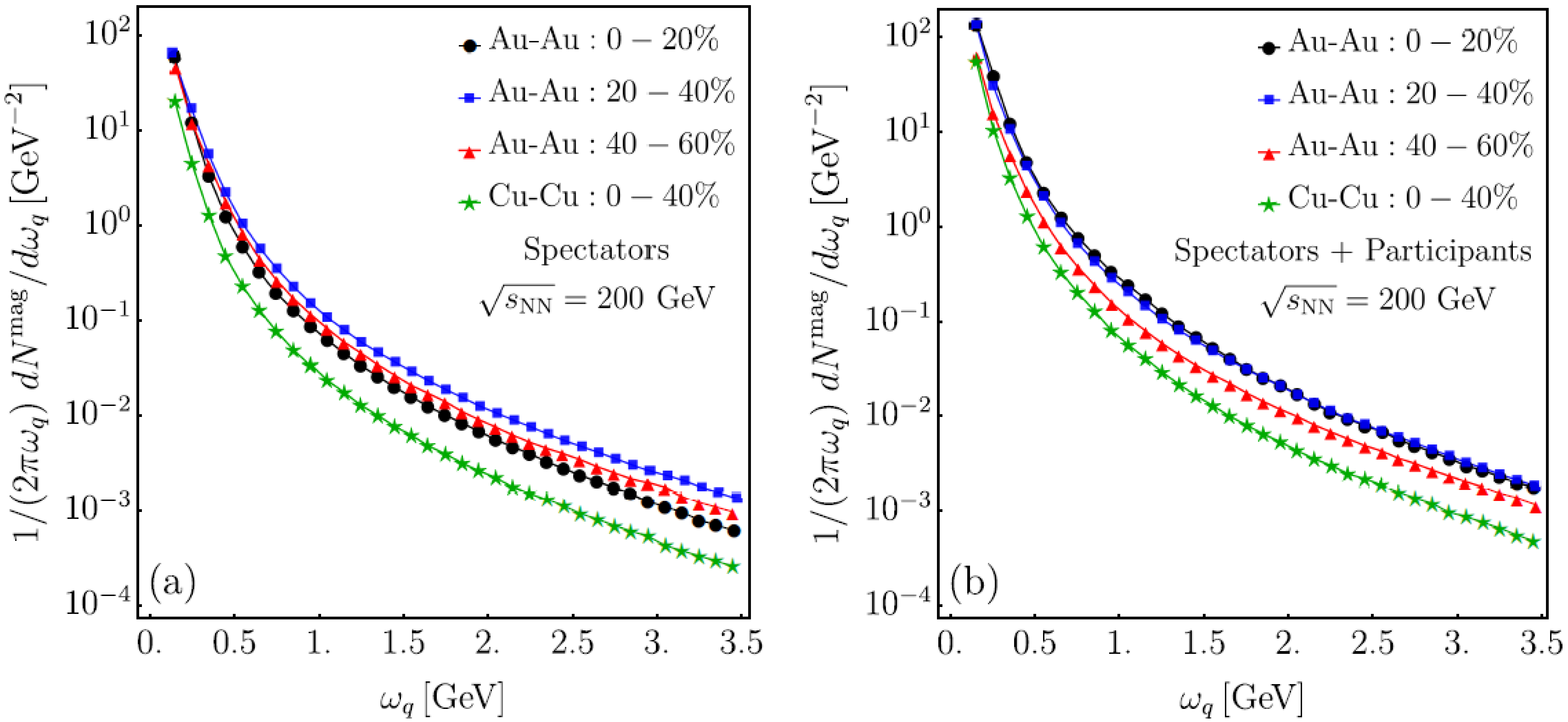
Au-Au
Spectators
$\sqrt{s_{NN}} = 200$ GeV
0 – 20%
(a)
$|eB|_{total}$
$|eB_z|$
$|eB_y|$
$|eB_x| \times 10^{-2}$
eB/m_π^2
t [fm]
Au-Au
Participants + Spectators
$\sqrt{s_{NN}} = 200$ GeV
0 – 20%
(b)
$|eB|_{total}$
$|eB_z|$
$|eB_y|$
$|eB_x| \times 10^{-2}$
eB/m_π^2
t [fm]



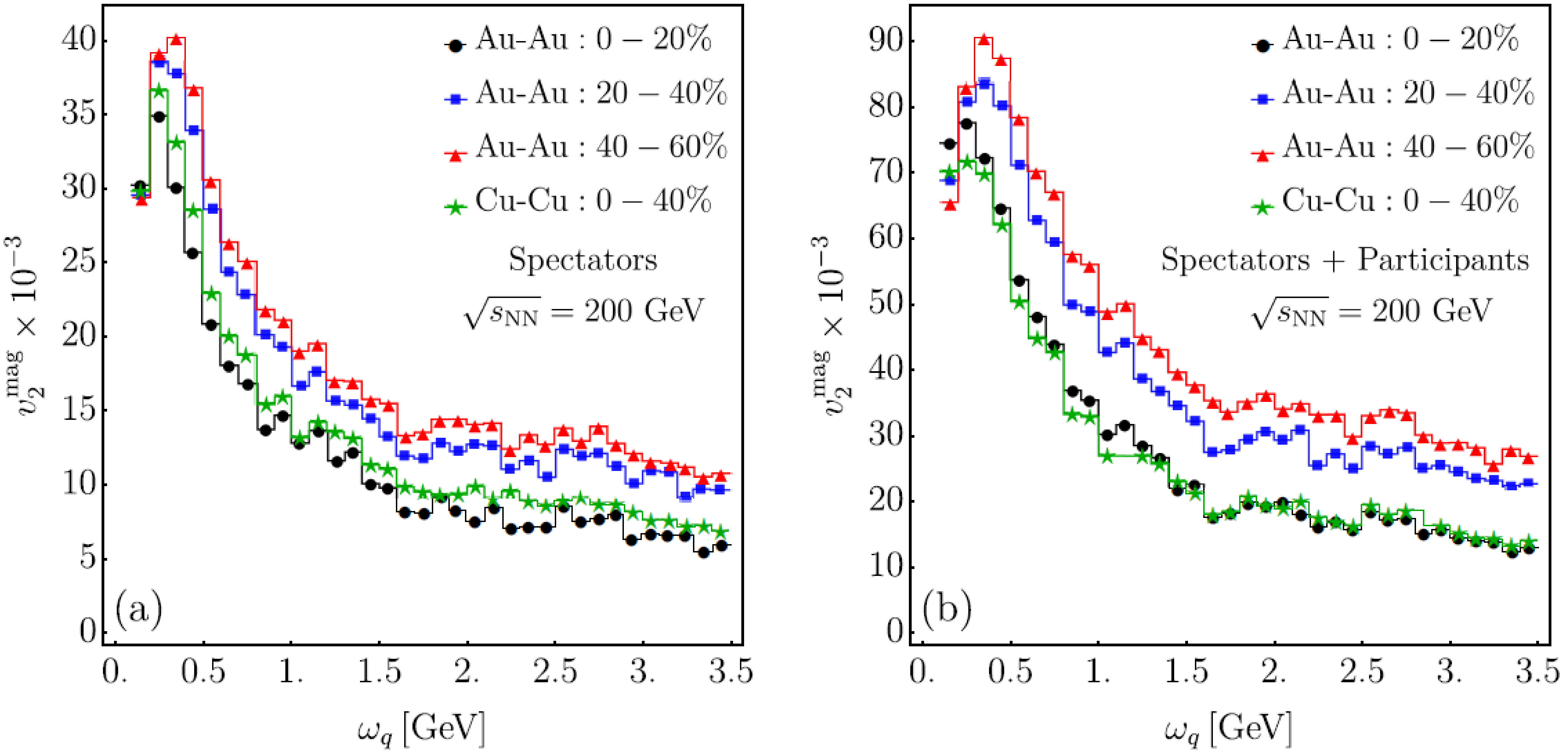
Au-Au
Spectators
$\sqrt{s_{NN}} = 200$ GeV
20 − 40%
(c)
$|eB|_{total}$
$|eB_z|$
$|eB_y|$
$|eB_x| \times 10^{-2}$
eB/m_π^2
t [fm]
Au-Au
Participants + Spectators
$\sqrt{s_{NN}} = 200$ GeV
20 − 40%
(d)
Au-Au
Spectators
$\sqrt{s_{NN}} = 200$ GeV
40 − 60%
(e)
Au-Au
Participants + Spectators
$\sqrt{s_{NN}} = 200$ GeV
40 − 60%
(f)



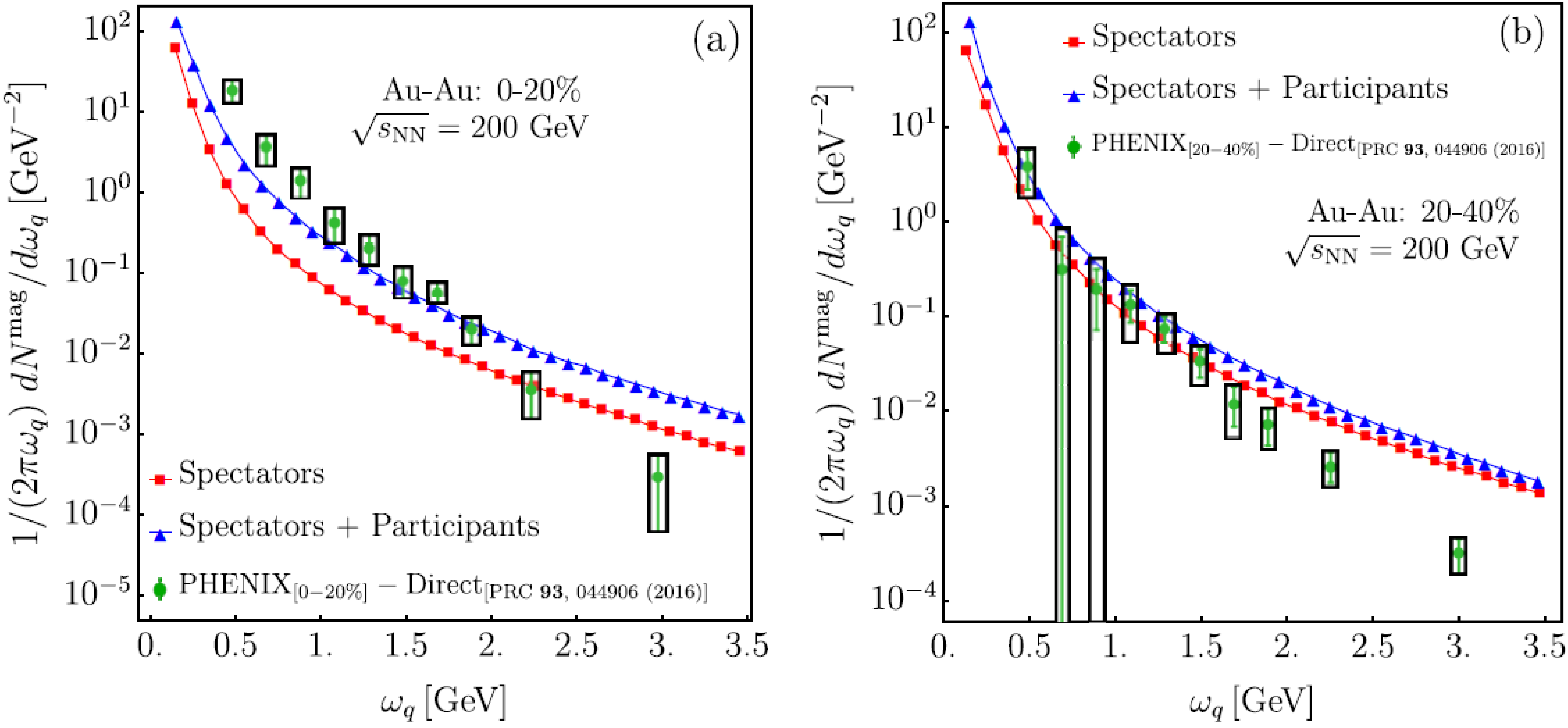
$$\mathcal{V}(t) = 2t\pi r_{\rm A}^2 \left(\frac{N_{\rm part}}{2N} \right)^{2/3}$$



Au-Au : 0 − 20%
Au-Au : 20 − 40%
Au-Au : 40 − 60%
Cu-Cu : 0 − 40%
Spectators
$\sqrt{s_{NN}} = 200$ GeV
(a)
Spectators + Participants
(b)
$1/(2\pi\omega_q)\ dN^{\rm mag}/d\omega_q\ [\rm GeV^{-2}]$
ω_q [GeV]



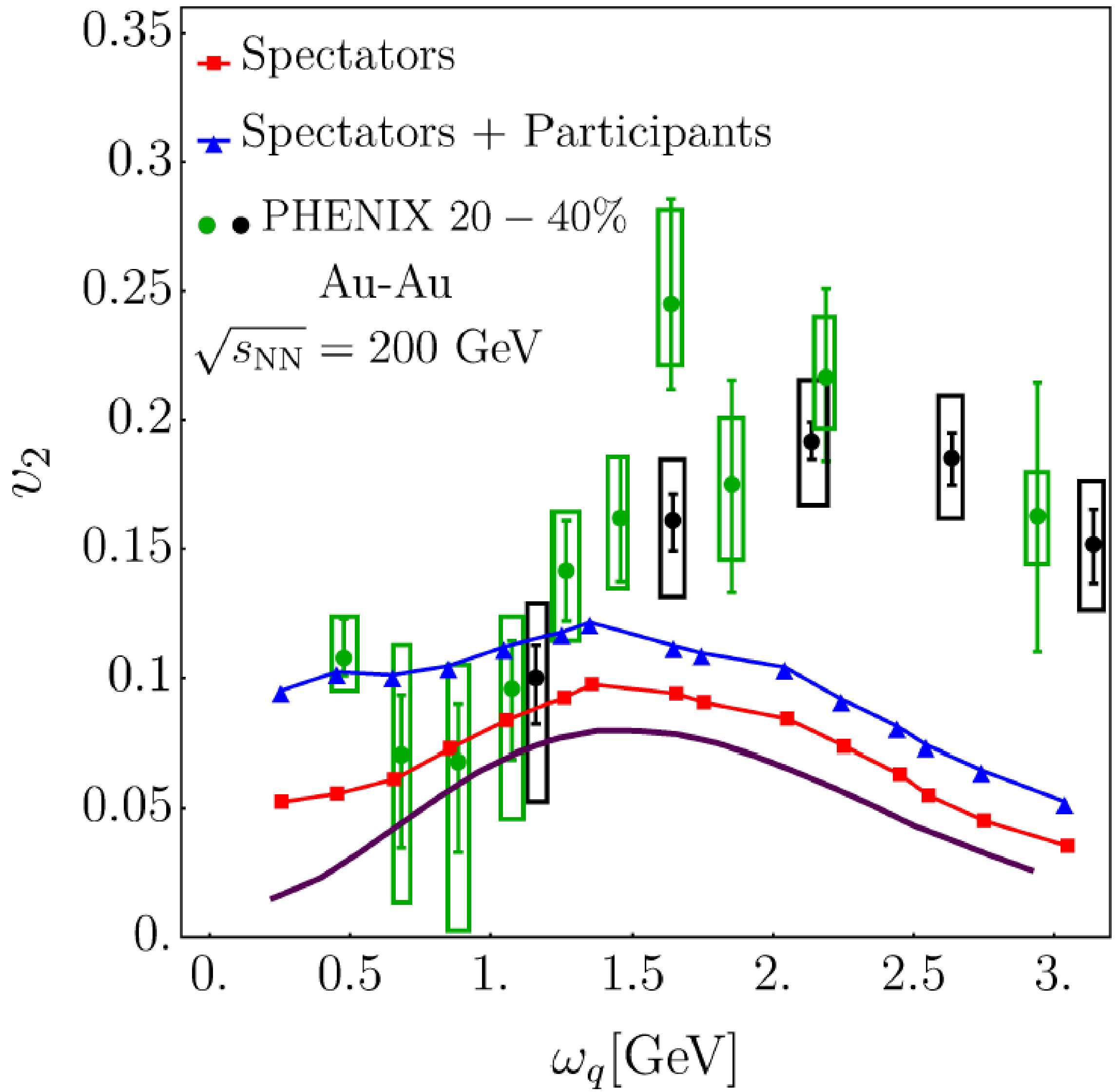
$$v_2^{\mathrm{mag}}(\omega_q) = \frac{\sum_{i=1}\left[\frac{dN^{\mathrm{mag}}}{d\omega_q}(\omega_q)\right]_i \left[v_2^{\mathrm{mag}}(\omega_q)\right]_i}{\sum_{i=1}\left[\frac{dN^{\mathrm{mag}}}{d\omega_q}\right]_i}$$



[PHENIX collaboration, PRC 91, 064904 (2016)]

Finally,

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



Conclusions

- We have computed the contribution to the photon yield and elliptic flow from gluon fusion and splitting induced by a magnetic field during the early stages of a relativistic heavy-ion collision.

- The magnetic field strength and volume are computed using UrQMD simulations and the results compared with recent data from PHENIX.

- The results show a relatively good agreement for the lower part of the spectra and is better for peripheral collisions.

THANK YOU
FOR
YOUR
ATTENTION
ANY QUESTIONS?