Preliminary results on Dilepton production from strong fields in heavy-ion collisions

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Based on work with Y.Hidaka and K.Tuchin

Plan

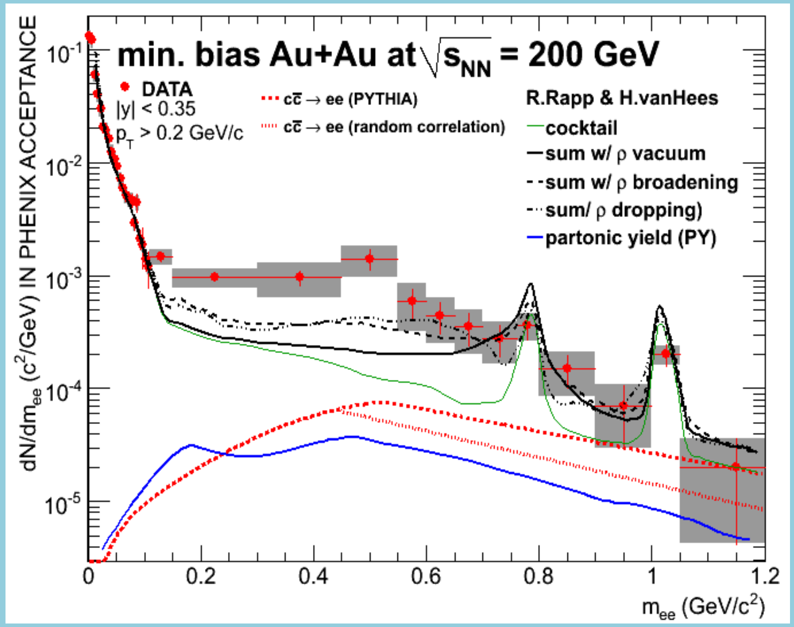
- Motivation
- Two strong fields in HICs
- New mechanism of dilepton production
  - from magnetic fields
  - from color magnetic fields

Motivation

Dilepton yield measured by PHENIX has large enhancement at low mass region

→ Any new source of dileptons?

New dynamics from strong magnetic fields present at very early stages of HIC events?



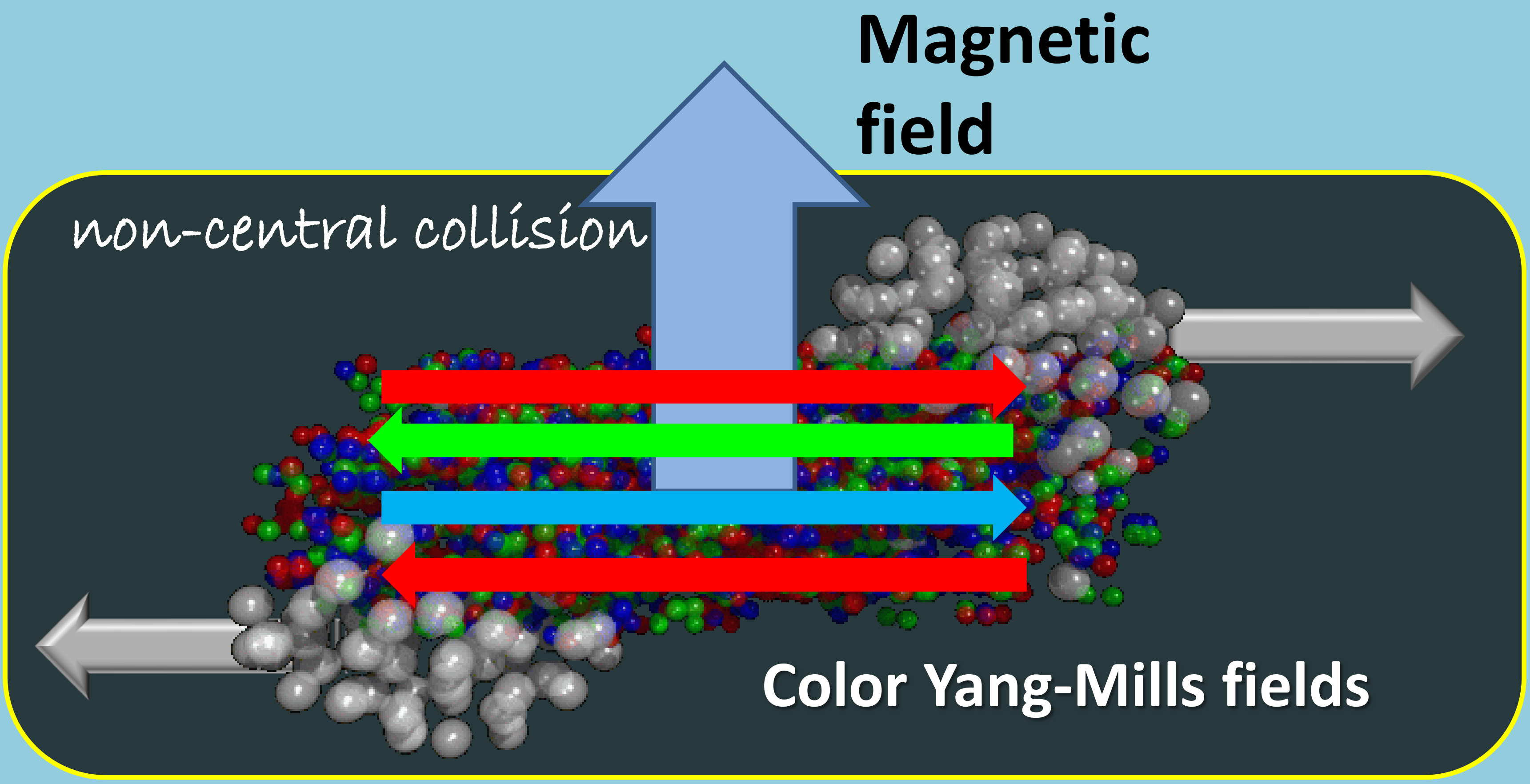
→ Is it possible to have dileptons from strong magnetic fields?

→ How about the COLOR magnetic fields (Glasma)?

Also, need to understand consistently with direct photon production

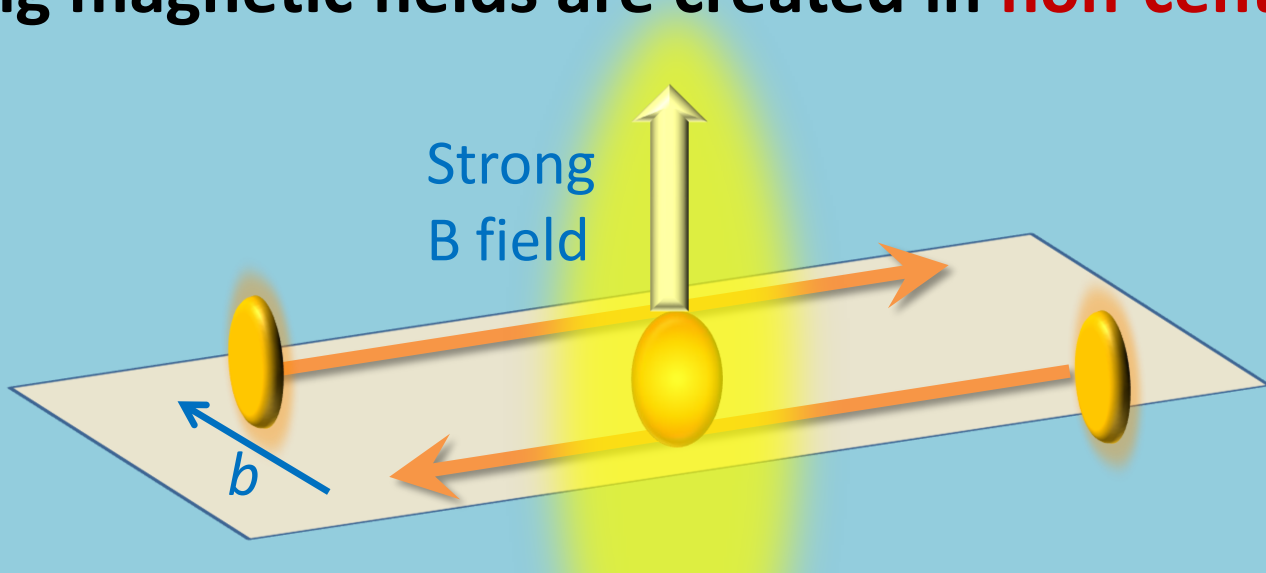
→ Direct photons are really from thermal QGP?

Two strong fields



Strong magnetic fields in HIC's

Strong magnetic fields are created in non-central HIC



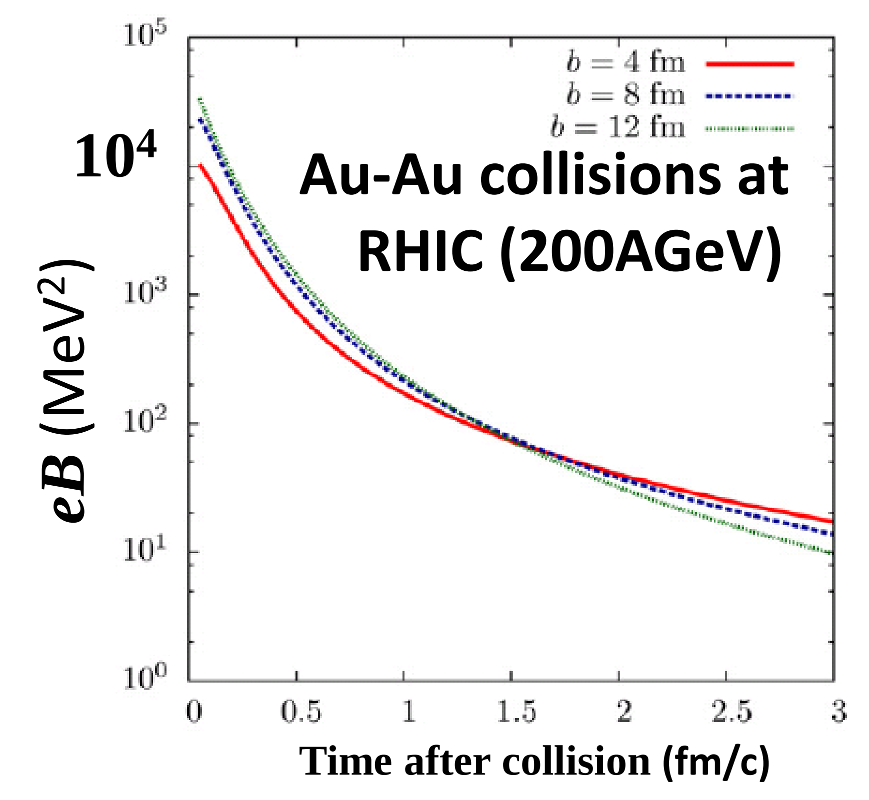
Lorentz contracted electric field is accompanied by strong magnetic field

$$e\vec{B}(\vec{x}) = Z\alpha_{\mathrm{EM}}\boxed{\sinh(Y)}\frac{(\vec{x}'_{\perp}-\vec{x}_{\perp})\times\vec{e}_z}{[(\vec{x}'_{\perp}-\vec{x}_{\perp})^2+(t\sinh Y - z\cosh Y)^2]^{3/2}}.$$

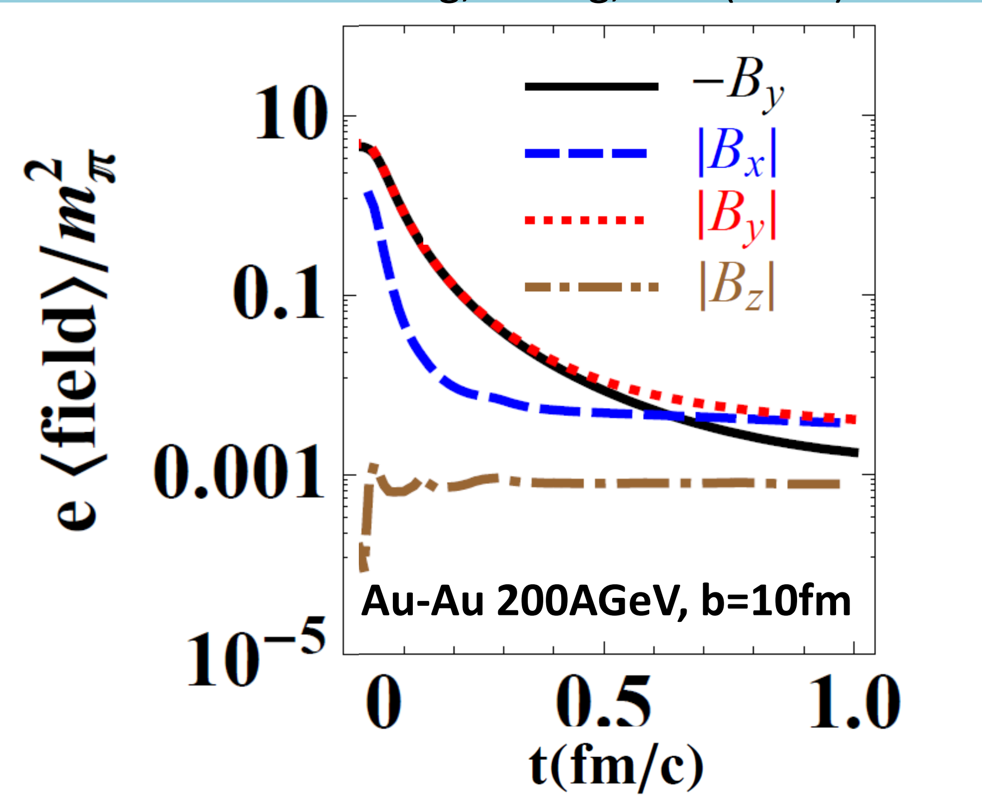
$x_{\perp}'$, Y : transverse position and rapidity (velocity) of moving charge

Time dependence

Kharzeev, McLerran, Warringa, NPA (2008)



Event-by-event analysis with HIJING
Deng, Huang, PRC (2012)



$\sqrt{eB} \sim 1 - 10\ m_\pi >>>> m_e = 0.5\mathrm{MeV}$

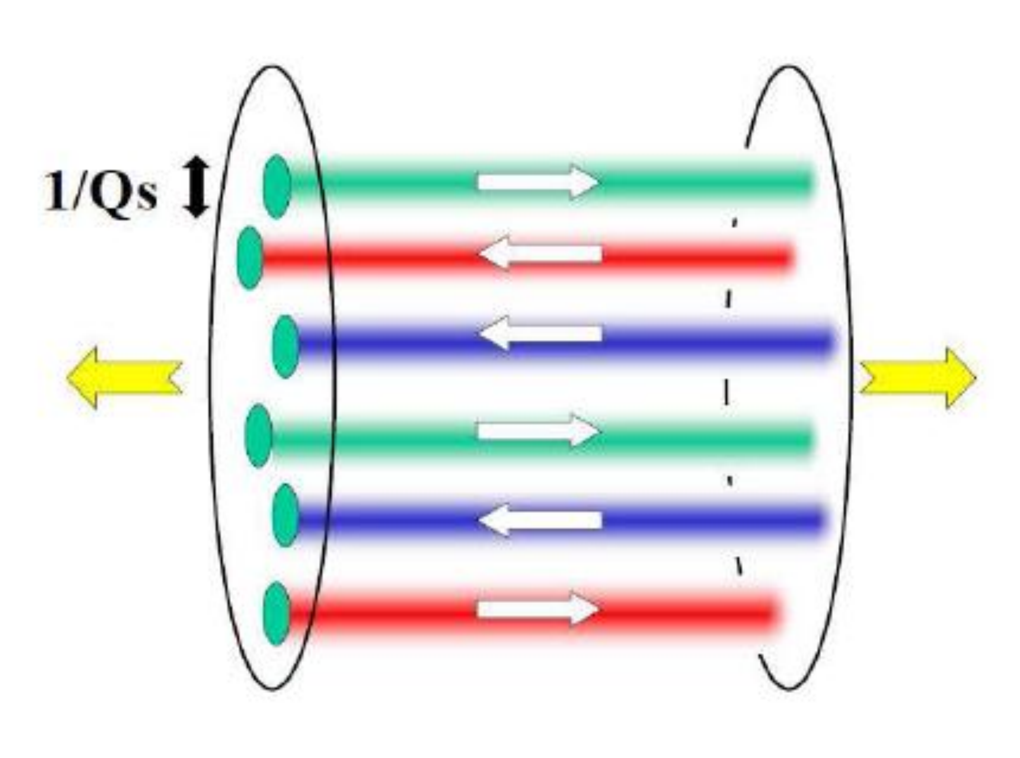
Strong enough for electrons even at the time of QGP formation

→ give a big impact on EM dynamics

Strong Yang-Mills fields (Glasma)

Just after the collision:
"GLASMA"

CGC gives the initial condition
→ "color flux tube" structure
with strong color fields



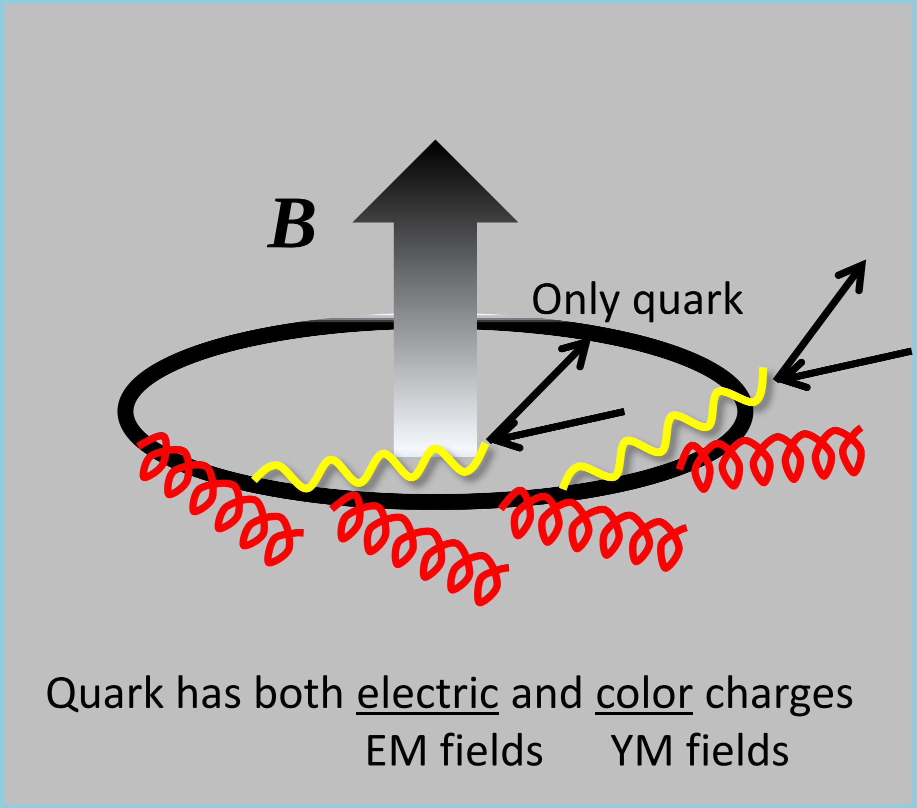
$$\sqrt{gB} \sim \sqrt{gE} \sim Q_s$$

~ 1 GeV – a few GeV

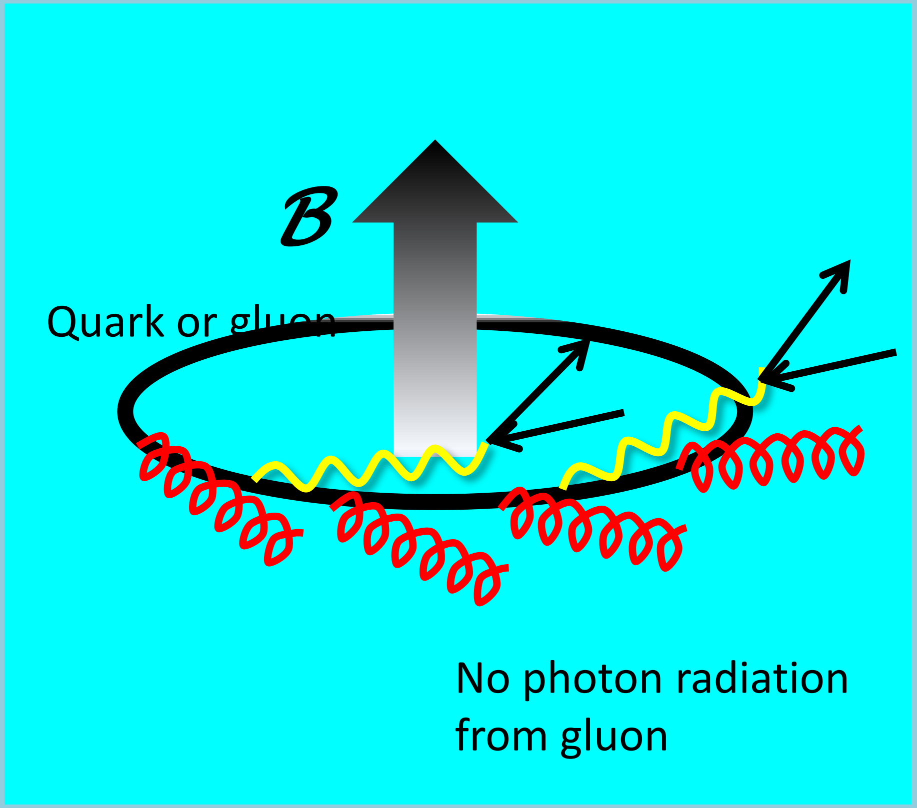
RHIC LHC

What happens in strong *B* fields?

Magnetic field bg



Color magnetic field bg



Also **virtual photons** are emitted → generate dilepton pairs

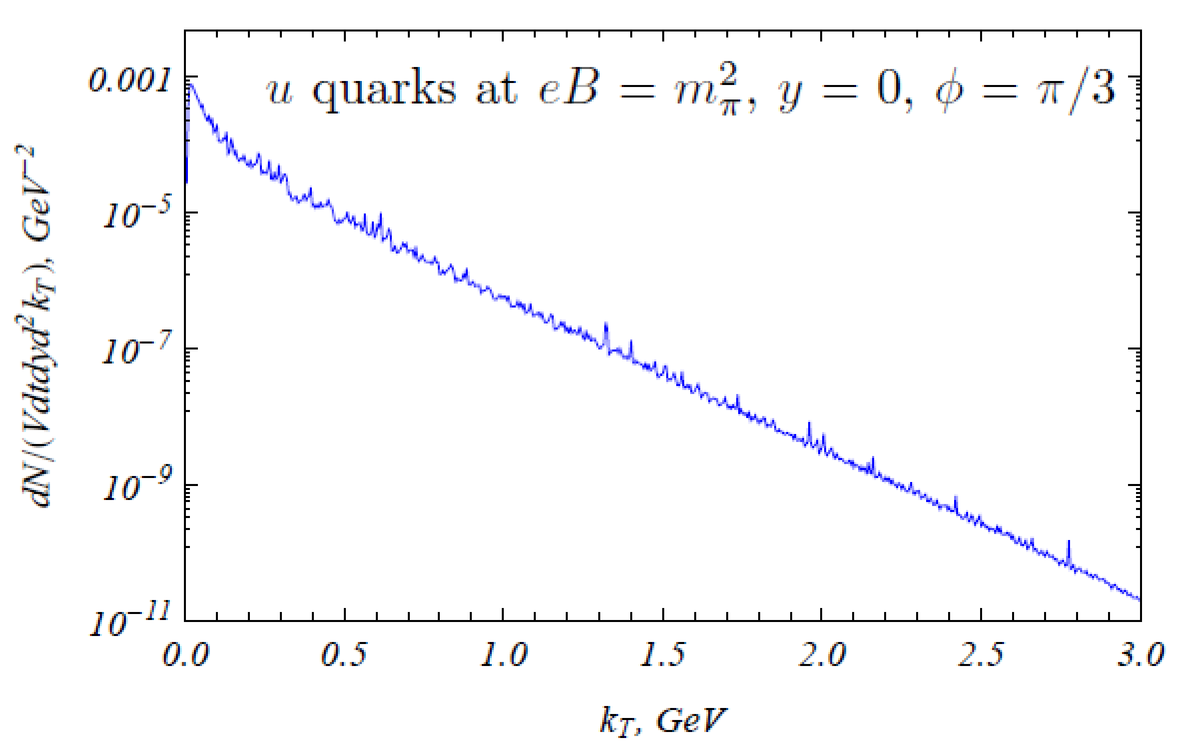
Even real photons can decay into an e+e- pair in magnetic fields

Gluons will fragment into pions…

Real photons from Synchrotron radiation

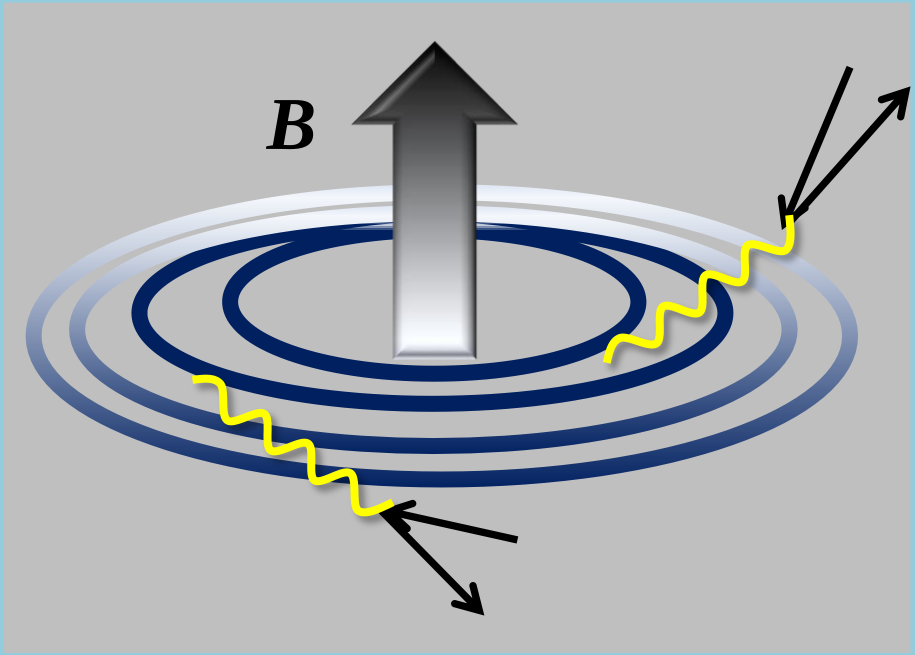
Synchrotron radiation (real photon) from QGP

K.Tuchin, arXiv:1206.0485



There must be virtual photon production which will yield dileptons

Setup of calculation



- Quark's Synchrotron radiation of virtual photons decaying into e+e- pairs
- Assume time-independent homogeneous magnetic field
- Assume QGP at temperature *T*

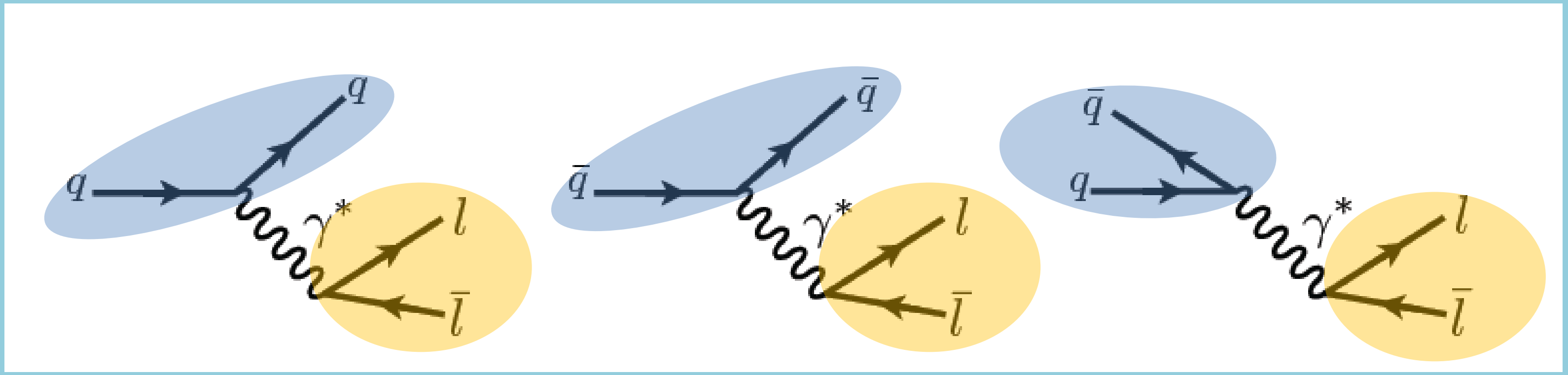
  but treat both quarks and leptons in Landau levels and include the effects of magnetic field through one-particle energy

$$f_q(E_n) \propto \frac{1}{e^{E_n/T}+1}, \quad E_n = \sqrt{k_z^2 + m^2 + 2neB}$$

- Ignore the magnetic effects on intermediate photon propagator

Outline of calculation

Synchrotron radiation from quark and antiquark Pair annihilation



Production rate

$$\frac{d\Gamma}{d^4q} = \frac{1}{(2\pi)^4} \Pi^{\mu\rho}(q) D_{\mu\nu}(q) D^*_{\rho\sigma}(q) L^{\nu\sigma}(q),$$

Lepton/quark tensor → vacuum polarization tensor (see talk by K.Hattori)

$$l^{\mu\nu}(k_1, k_2) = \mathrm{tr}\, S_{n_1}(k_1, m_l)\gamma^\mu(-S_{n_2}(-k_2, m_l))\gamma^\nu,$$

propagator $\frac{S_n(k)}{k^2+m^2}$

$$\Pi^{\mu\nu}(q) \equiv \sum_{f=u,d} q_f^2 e^2 \sum_{n_1,n_2} \int \frac{d^3p_1}{(2\pi)^3 2E_{n_1}(p_1, m_f)} \int \frac{d^3p_2}{(2\pi)^3 2E_{n_2}(p_2, m_f)}$$
$$\times \Big[\pi_f^{\mu\nu}(p_1, p_2)(2\pi)^4\delta^{(4)}(q - p_1 - p_2) f(E_{n_1}(p_1, m_f)) f(E_{n_2}(p_2, m_f))$$
$$- 2\pi_f^{\mu\nu}(p_1, -p_2)(2\pi)^4\delta^{(4)}(q - p_1 + p_2) f(E_{n_1}(p_1, m_f))(1 - f(E_{n_2}(p_2, m_f))\Big],$$

Preliminary results

Yield

Here numerical result was displayed which shows enhancement of soft Di-electron production

$$M^2 = \omega^2 - q_z^2 - q_T^2$$

Invariant mass of the virtual photon
= Invariant mass of dileptons in the absence of magnetic field

Total di-electon yield from u, ubar, d, dbar
(averaged over 30MeV as resolution)

Blue: without magnetic field (only from qqbar annihilation)

Red: qqbar annihilation contribution in magnetic field

Purple: Synchrotron radiation

Sorry. Figures were removed.
If you want to know the detail please contact with the speaker at kazunori.itakura@kek.jp

With high resolution

Yield

Here numerical result with
high resolution scale was displayed
which shows many spikes from
Landau levels

$$M^2 = \omega^2 - q_z^2 - q_T^2$$

Sorry. Figures were removed.
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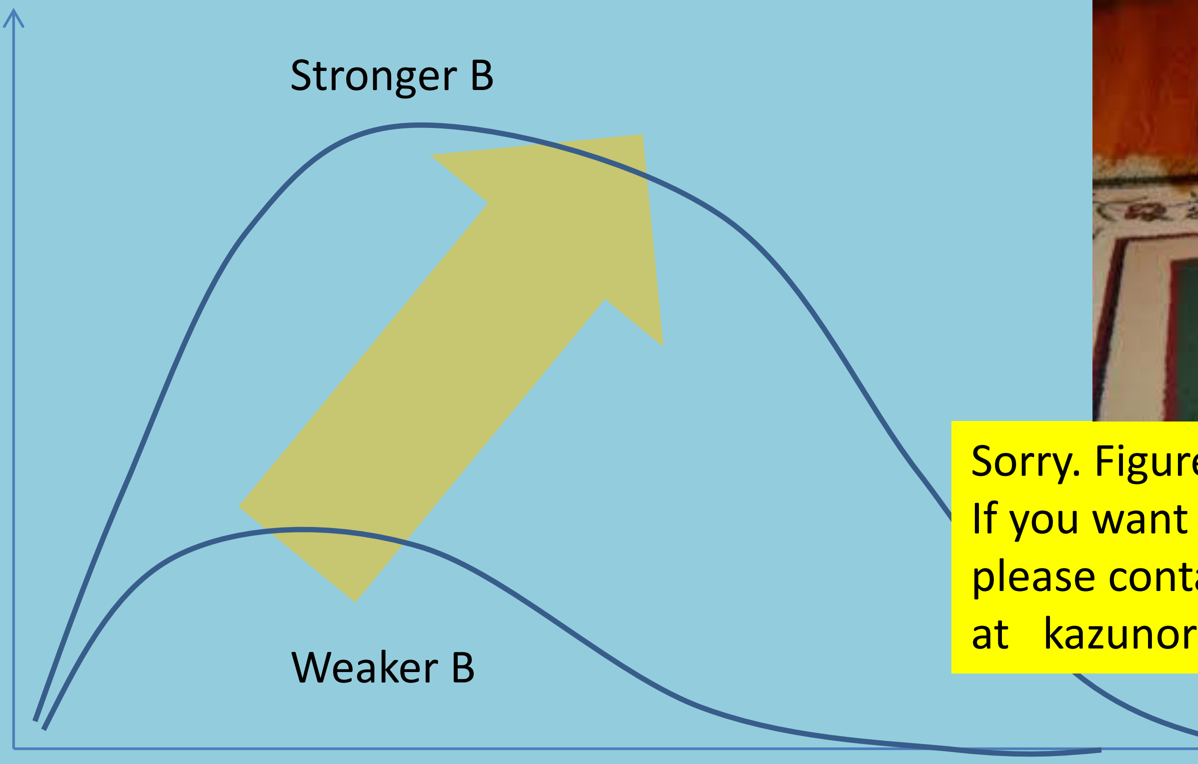
Resolution: 0.1 MeV

Spikes are from Landau levels

Dependence on the strength of B



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Dilepton production from Synchrotron radiation **<u>increases</u>** in $M^2<eB$ with **<u>increasing *B*</u>**

Implication

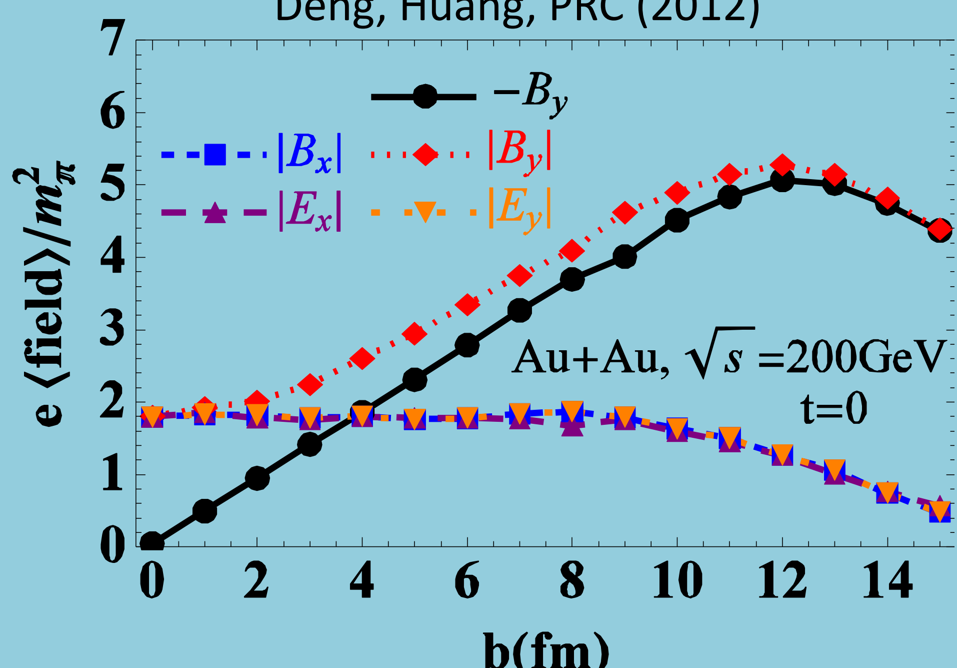
Does this solve the dilepton problem?

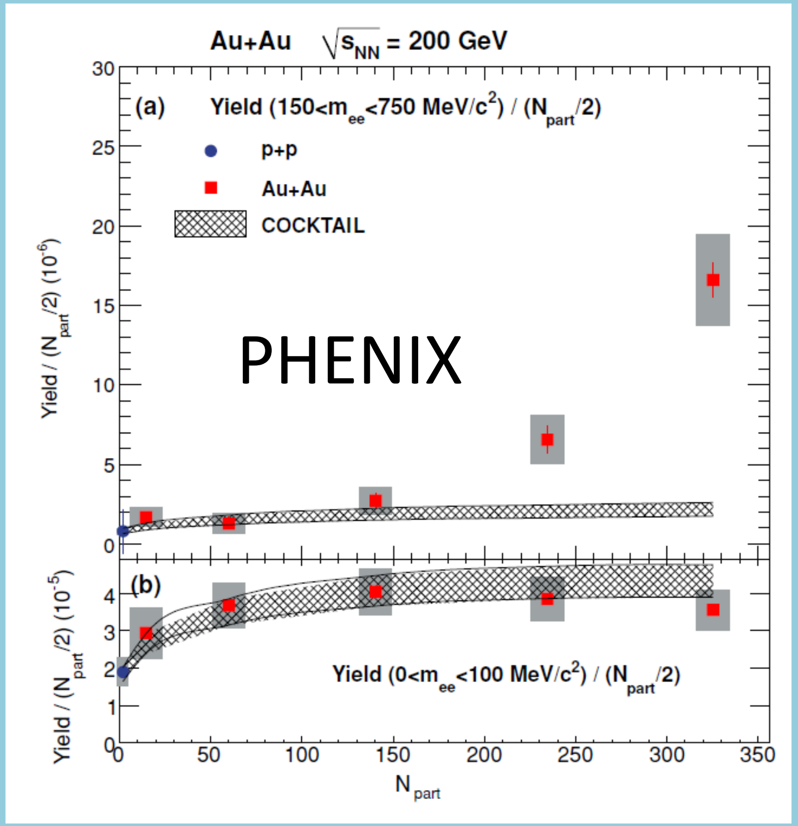
Not likely as it is, because the magnetic field becomes weak in most central collision, while the dilepton yield is the strongest.

(this will be true even with fluctuations included)

But this is certainly a new source of dilepton production.

Deng, Huang, PRC (2012)





Implication

Then, what's the possible solution?

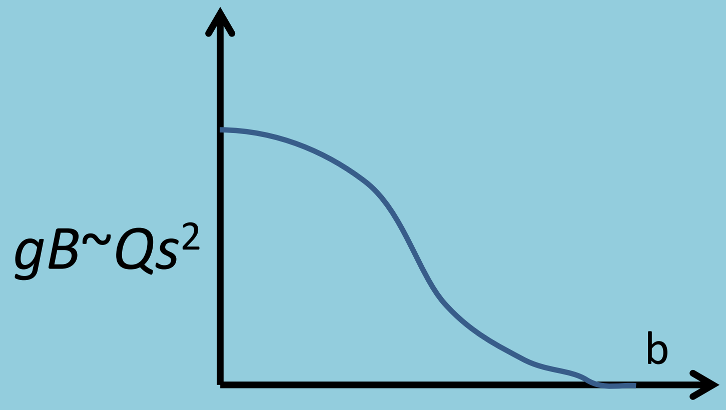
Synchrotron radiation from quarks in COLOR magnetic fields in Glasma should have

-- right centrality dependence

-- larger contribution due to stronger B

-- specific angular distribution

(color magnetic field is directed to the beam direction)



Thus, the dilepton contribution will appear in

$$M^2 < g\mathcal{B} \sim Qs^2 \sim 1\ \mathrm{GeV}^2 \text{ (at RHIC, central)}$$

This must be accompanied by **direct photon** production!!

(However, we should be careful about distribution of flux tubes)

Summary and prospects

- Dilepton production from Synchrotron radiation by q/qbar is computed
- Production yield enhances with increasing magnetic field strength, for invariant mass M^2 less than eB.
- Not immediately explain the measured PHENIX dilepton, but suggest the importance of similar process in glasma
- In reality, both contribution should be present. Dileptons from EM magnetic field is below $M^2 < eB$, while dileptons from Glasma magnetic flux is below $M^2 < g\mathcal{B}$. In general, $eB < g\mathcal{B}$. Two contributions!
- Also important to estimate dilepton production from
  - decay of real photons emitted in Synchrotron radiation (see talk by K.Hattori)
  - Electric fields via Schwinger mechanism (E is stronger in central than in peripheral on e-by-e basis)