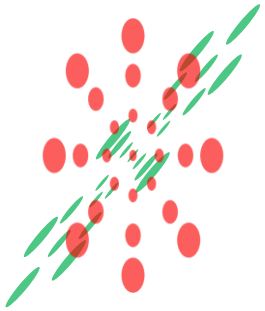
Backreaction of QGP fluids from recoil partons

Shoto Sakuma, Tetsufumi Hirano
Sophia University



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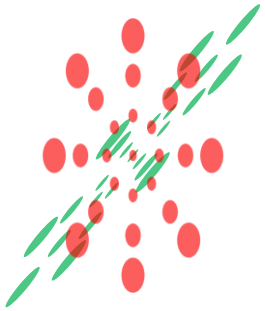
Introduction



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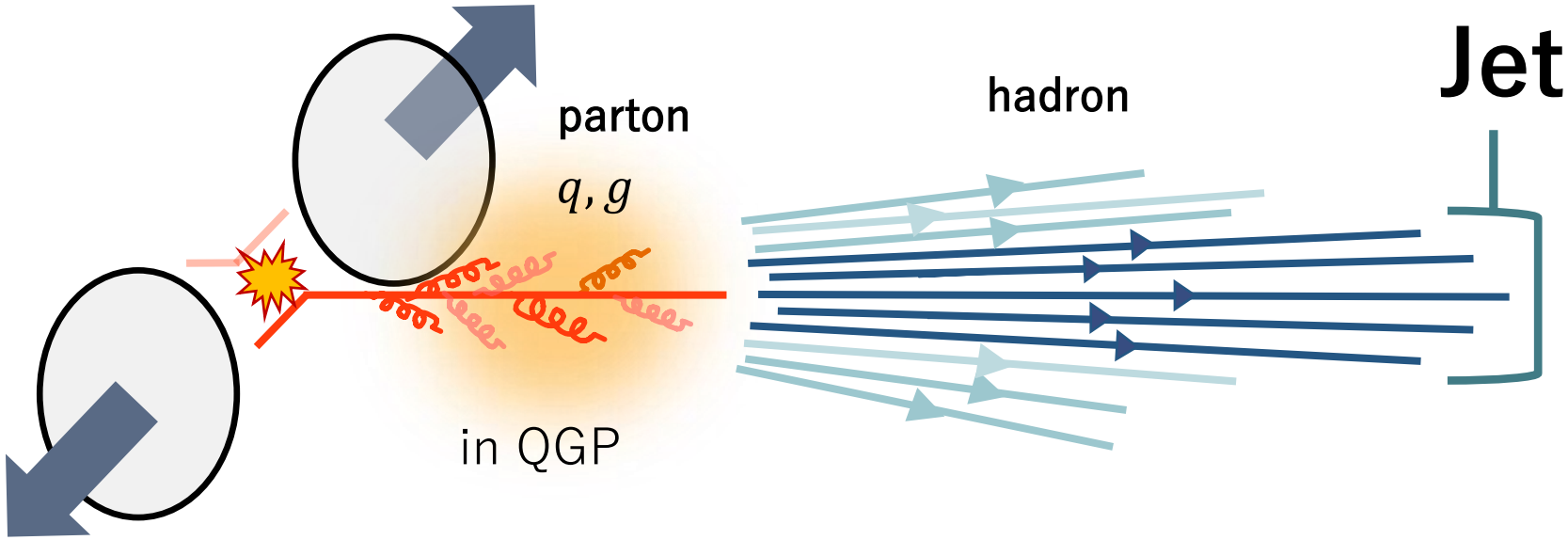
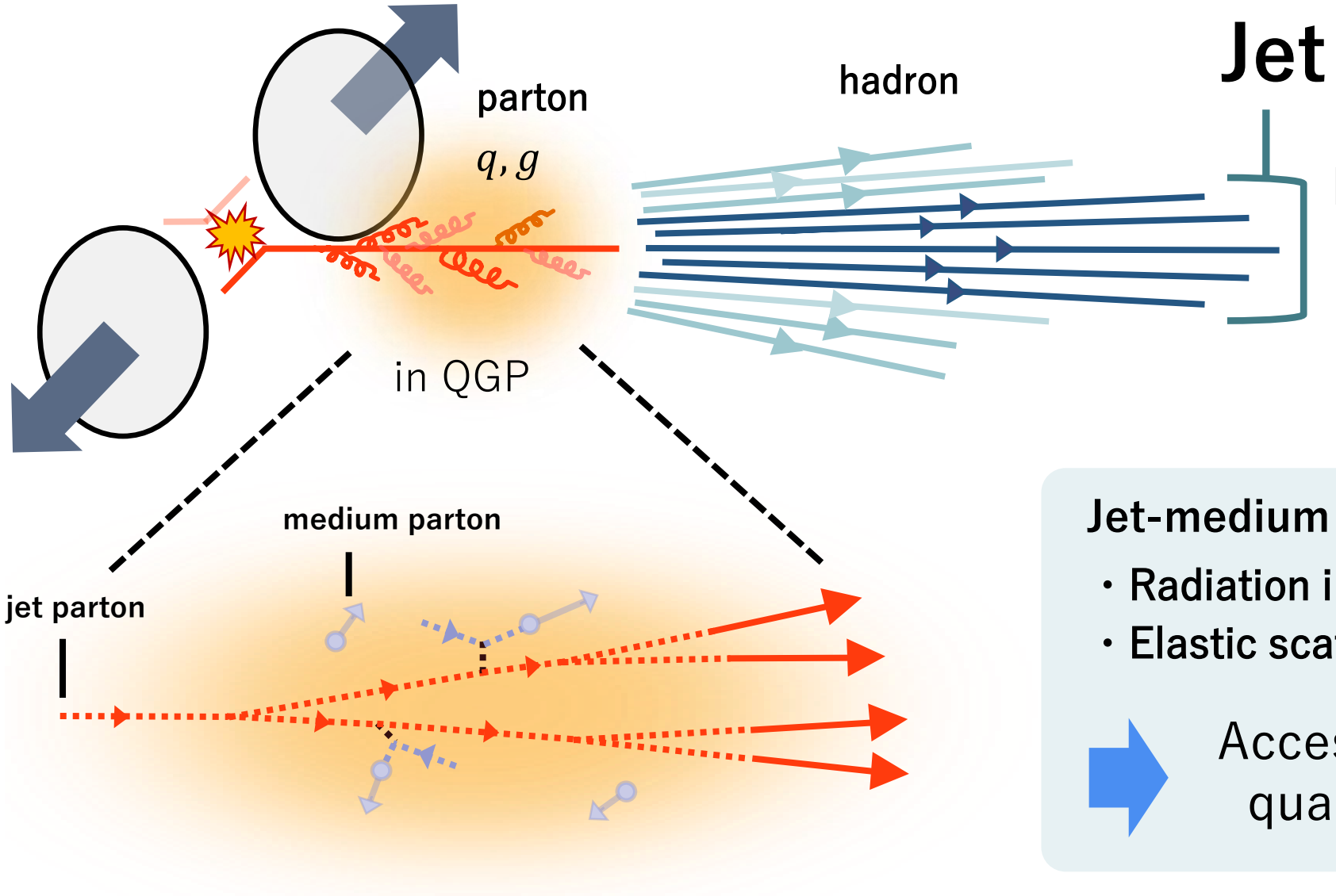
Jet in heavy-ion collision



Modification of jets holds information about “jet-medium interaction”

Jet in heavy-ion collision



Modification of jets holds information about "jet-medium interaction"

Jet-medium interaction

- Radiation induced by medium
- Elastic scattering

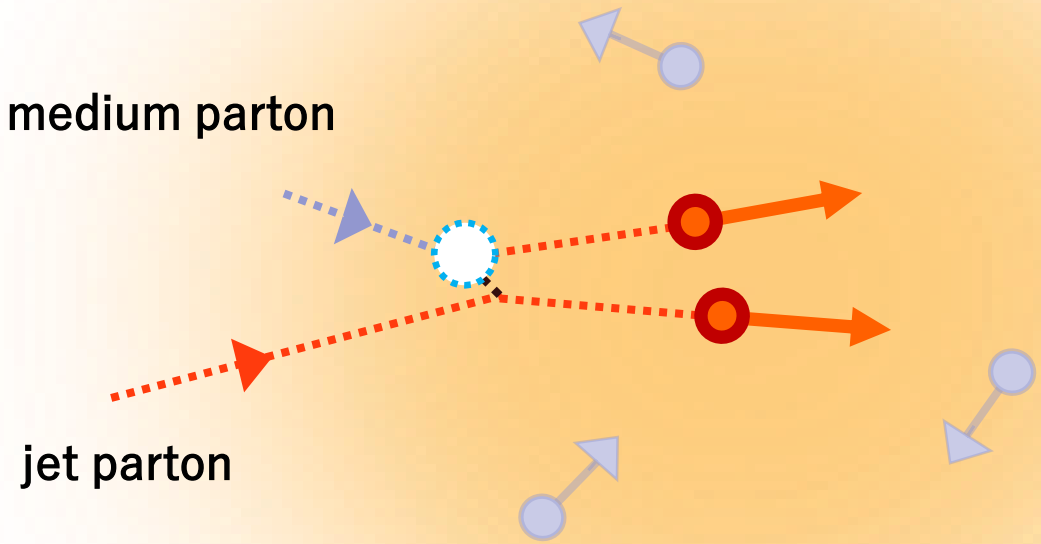
Access the information about quark-gluon plasma (QGP)

Recoil and backreaction

JEWEL
Korinna C. Zapp, Phys. Lett. B735 (2014)

LBT
T. Luo *et al.*, PLB782, 707-716 (2018)

QGP



Recoil

Medium parton kicked out by jet parton

- acquires high energy and momentum
- becomes non-equilibrated parton

Recoil and backreaction

JEWEL
Korinna C. Zapp, Phys. Lett. B735 (2014)

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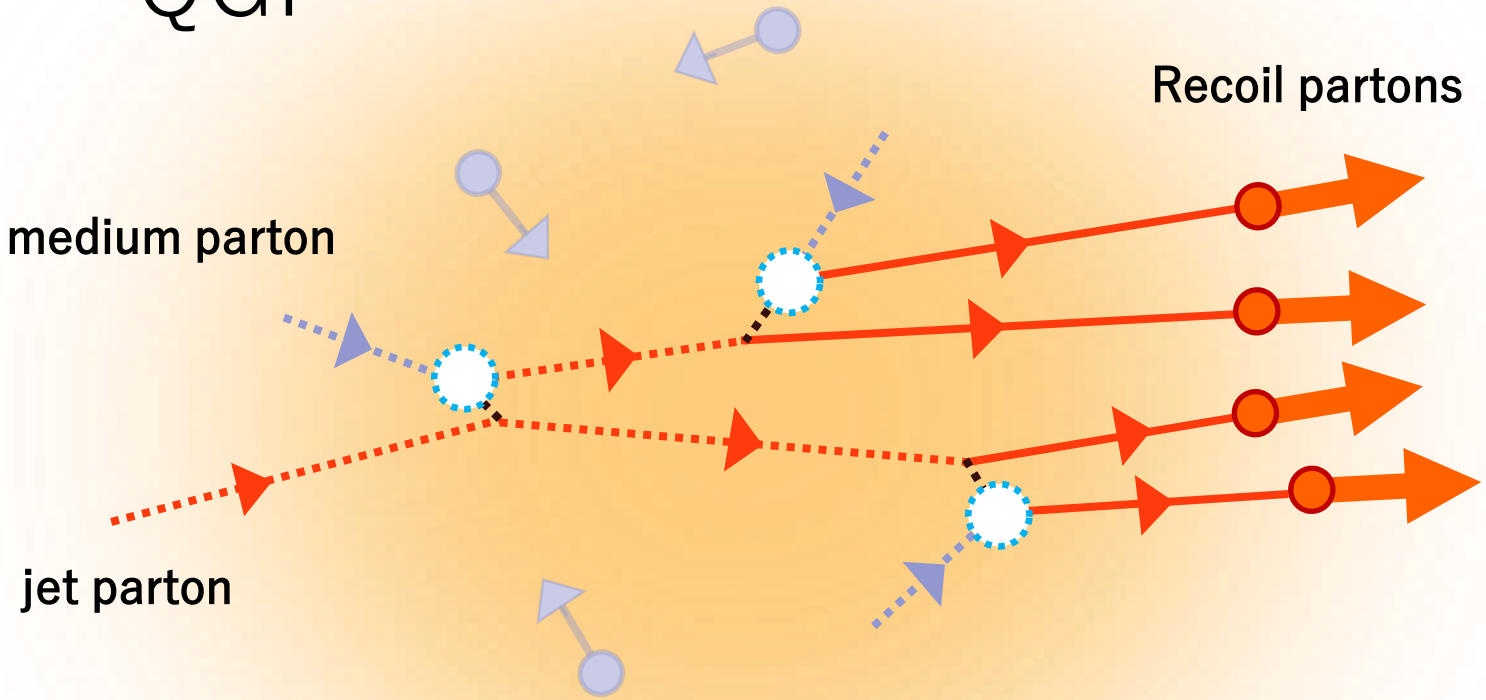
QGP



Recoil

Medium parton kicked out by jet parton

- acquires high energy and momentum
- becomes non-equilibrated parton

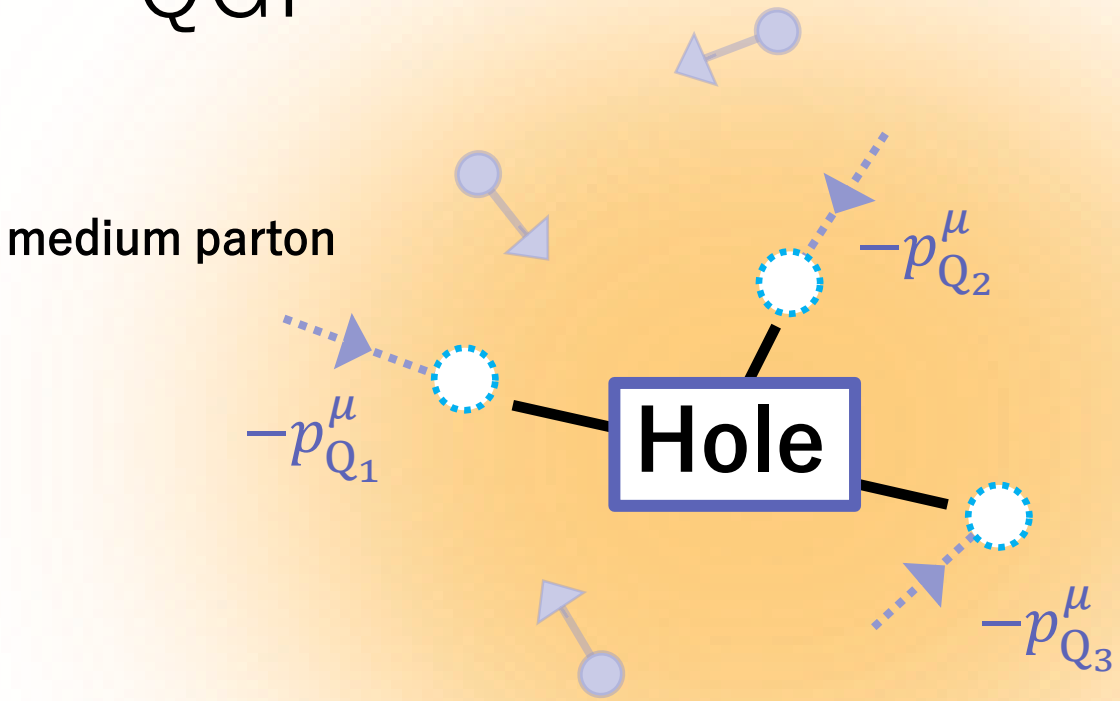
Energy and momentum of jet partons are modified

Recoil and backreaction

CoLBT-hydro

W. Chen, *et al.*, PLB 777, 86 (2018)

QGP



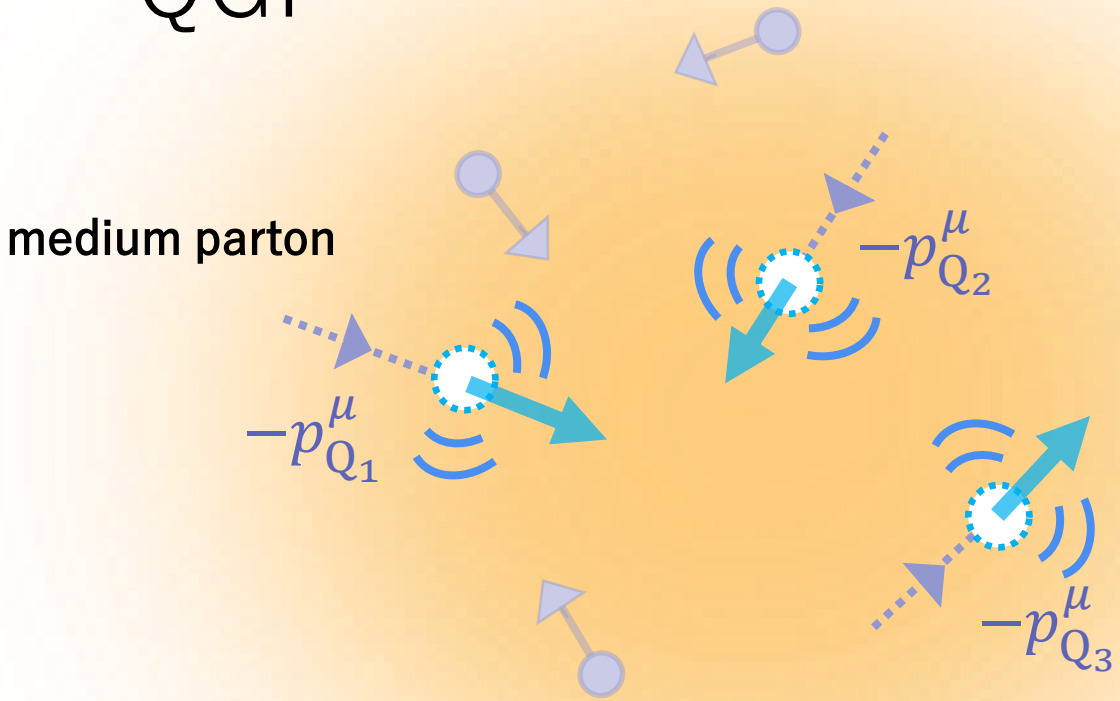
Recoil and backreaction

CoLBT-hydro

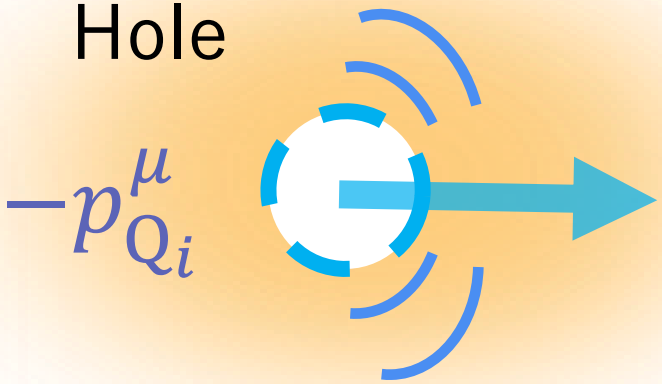
W. Chen, *et al.*, PLB 777, 86 (2018)

Backreaction

QGP



Hole

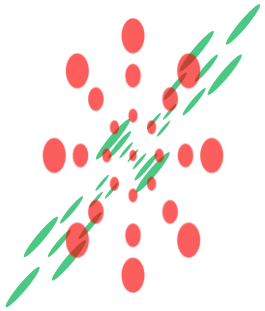


■ **Purpose** ■

Investigate the effect of
“dynamical” backreaction of QGP

To understand jet-medium interaction

Framework



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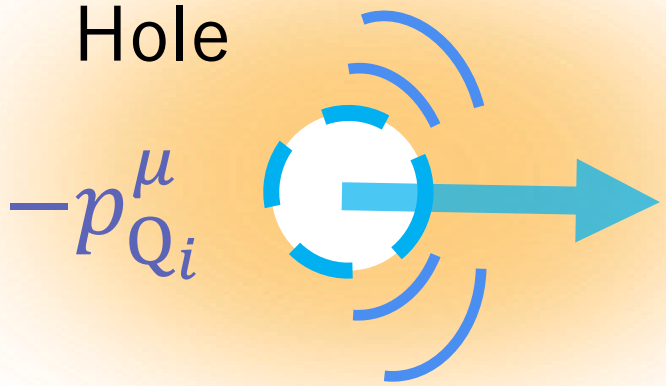
Negative source term for backreaction

Hydrodynamic eq. with **"negative" source term**

$$\partial_\mu T^{\mu\nu}_{\mathrm{QGP}} = \underline{-J^\nu}$$



Gaussian source

$$J^\nu = \sum_i \frac{dp^\nu_{\mathrm{Q}_i}}{dt} \underbrace{G(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{Q}_i})}_{\text{3D-Gaussian function}}$$

$$G(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{Q}_i}) = \left(\frac{1}{2\pi\sigma_{\mathrm{G}}^2}\right)^{\frac{3}{2}} \exp\left[-\frac{(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{Q}_i})^2}{2\sigma_{\mathrm{G}}^2}\right]$$

$p^\mu_{\mathrm{Q}_i}, \boldsymbol{x}_{\mathrm{Q}_i}$: energy-momentum and position of recoiled medium partons

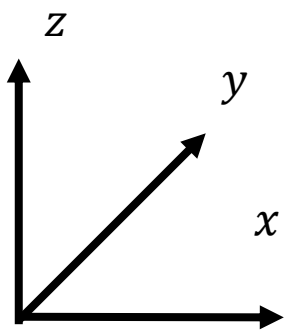
σ_{G}: width of gaussian

- (3+1)-D ideal hydro
- non-expanding system
- conformal EoS

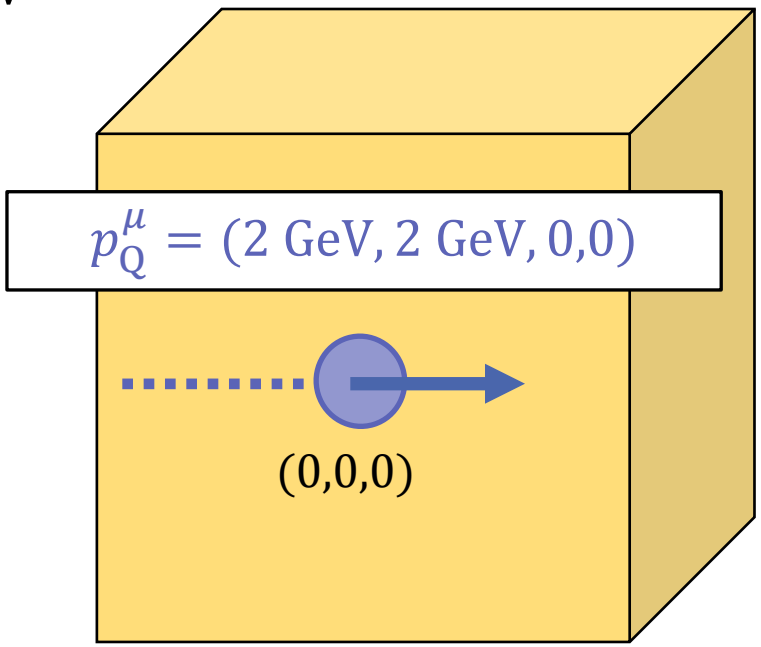
Test calculation

$T_0 = 500$ MeV
$\sigma_G = 0.3$ fm

1 medium parton



Static QGP brick



Test calculation

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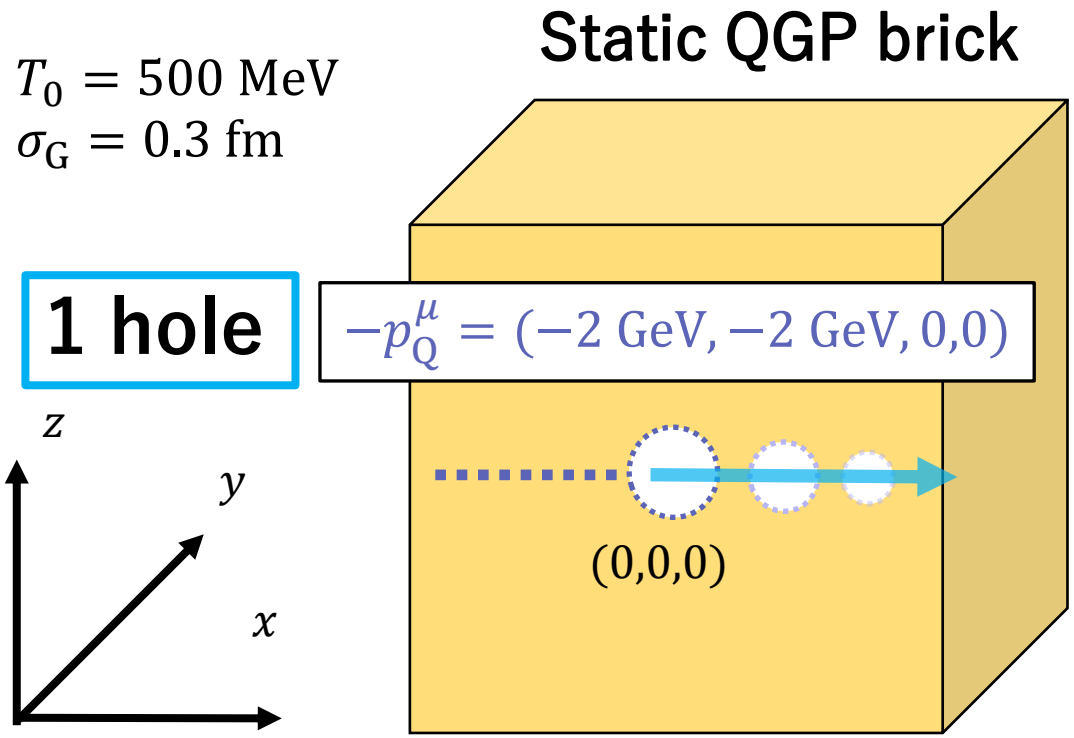

$$\partial_\mu T^{\mu\nu}_{\text{QGP}} = -J^\nu$$ "negative" source term

Test calculation

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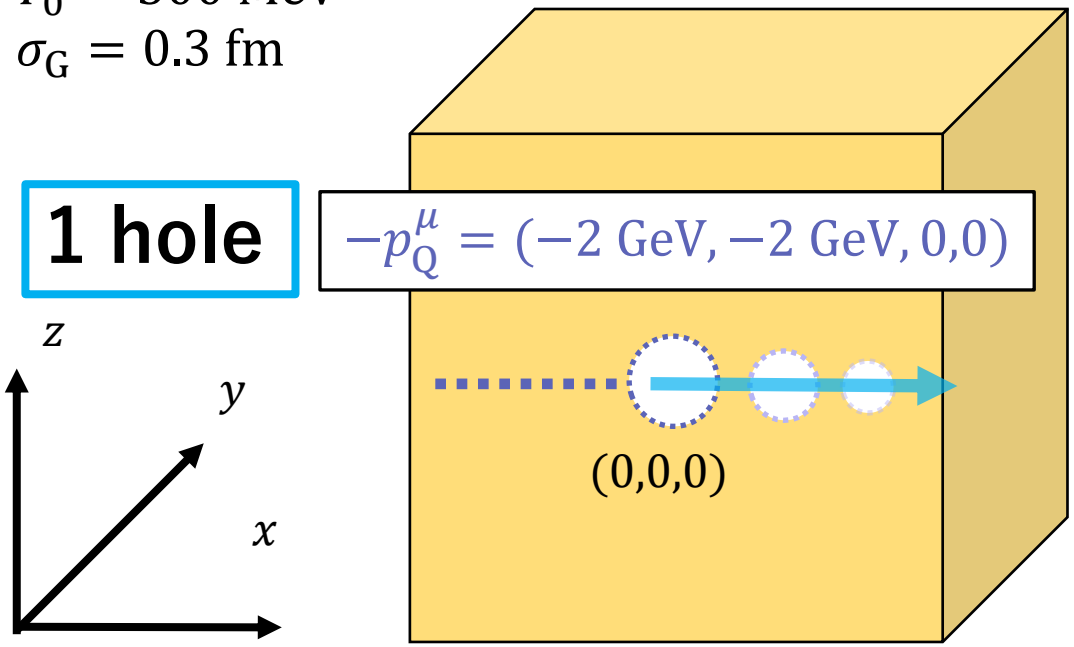
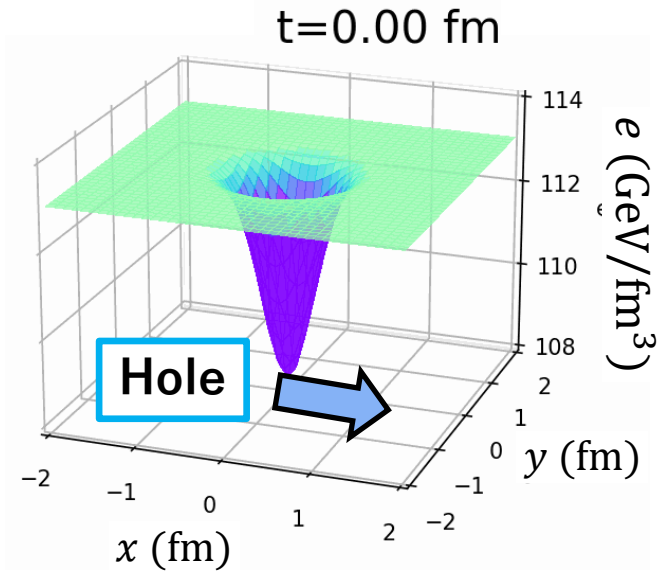
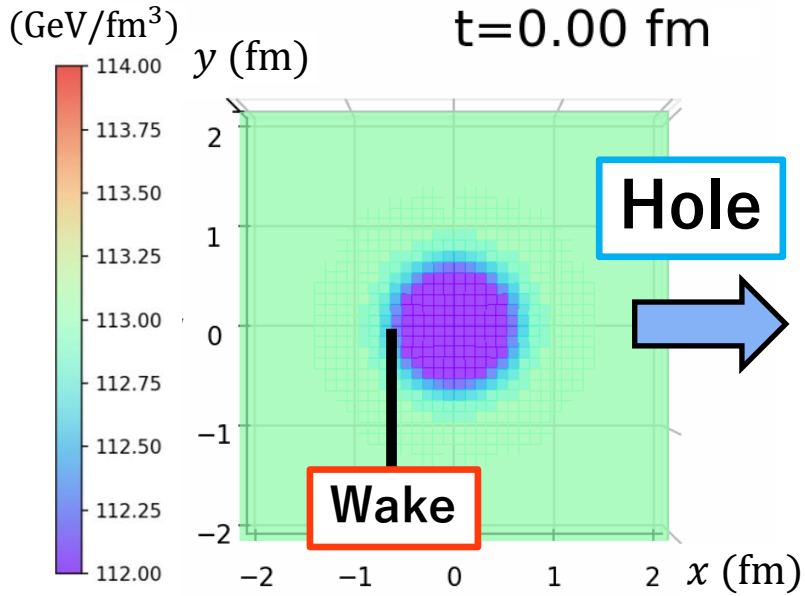
Static QGP brick



$$\partial_\mu T^{\mu\nu}_{\text{QGP}} = -J^\nu$$ "negative" source term

energy density of QGP



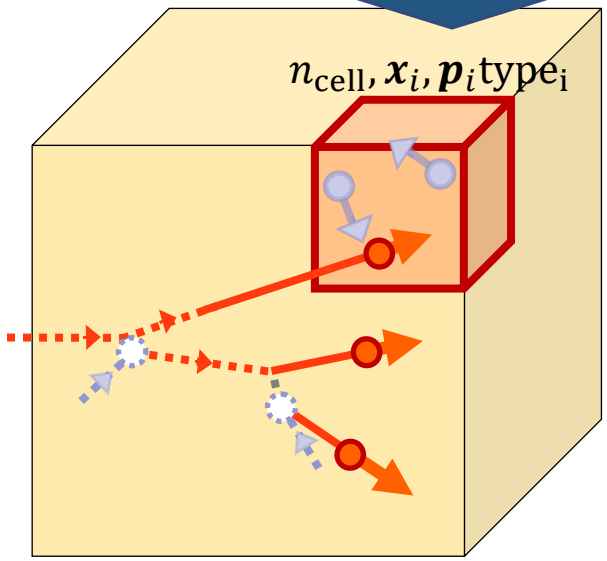


Elastic process

Static QGP brick

$T(x), v(x), \Delta V$

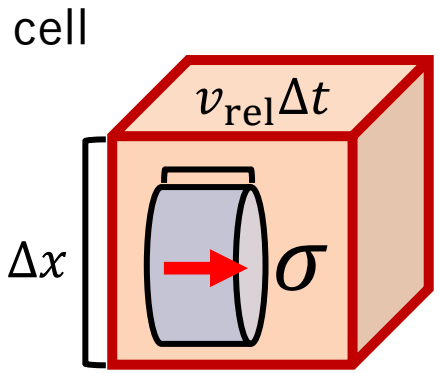
fermi dist, bose dist …



■ Collision detection

Stochastic method

to simulate Boltzmann equation



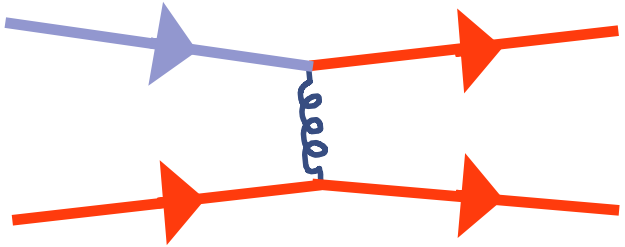
$$P = \frac{\text{cell}}{\text{cell}}$$

Collision probability

■ Elastic scattering

LO-pQCD + parton's Debye mass

$$\frac{d\sigma}{d\Omega_{\mathrm{CM}}} = \frac{\alpha_s^2}{4s}|M(ab \to cd)|^2$$



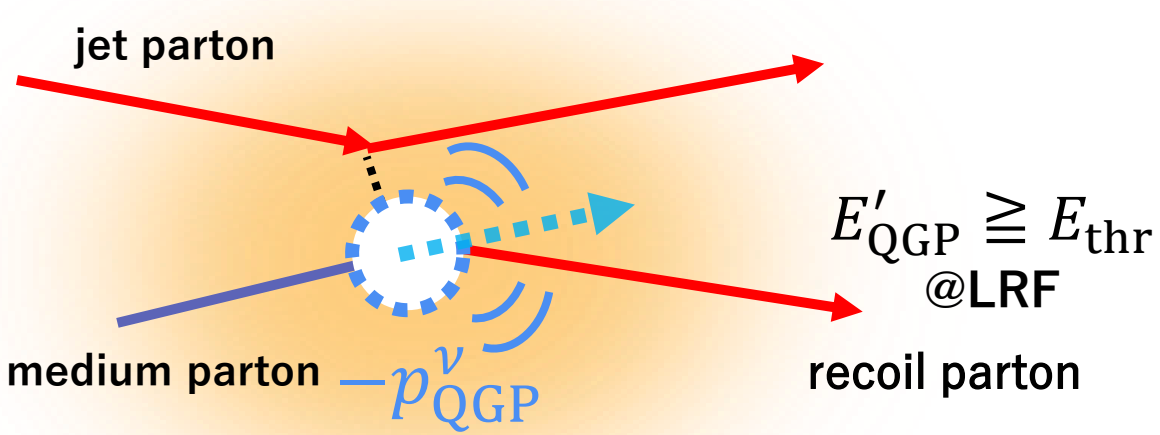
$gg \to gg,$
$q\bar{q} \to q\bar{q},$
$gq \to gq$ …

Z. Xu and C. Greiner,Phys. Rev. C **71**, 064901(2005)

Medium response

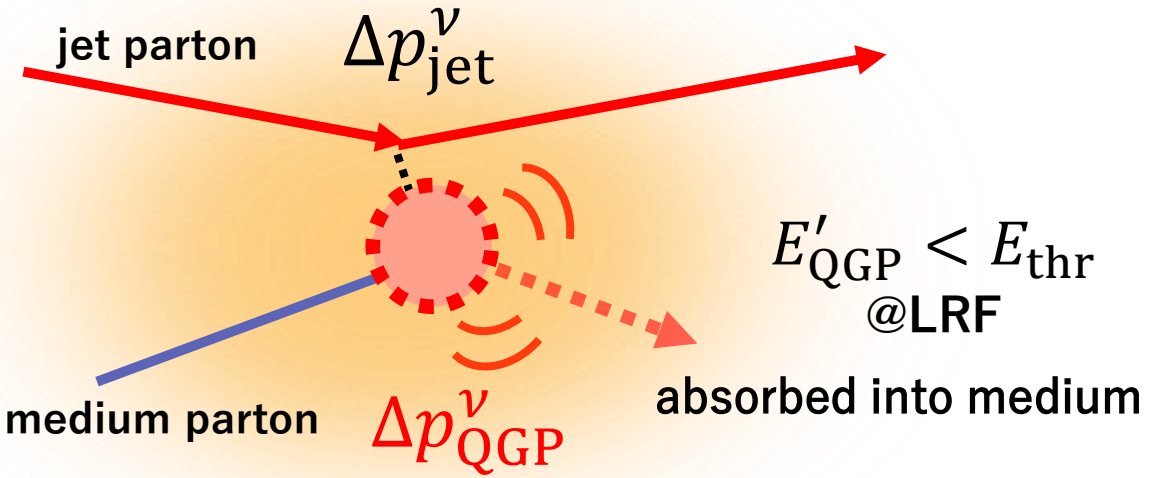
E_{thr}: threshold of recoil

Backreaction from recoil



$$\partial_\mu T^{\mu\nu} = \sum_i -\frac{dp^{\nu}_{\mathrm{Q}_i}}{dt} G(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{Q}_i})$$

Deposition from jet energy loss



$$\partial_\mu T^{\mu\nu} = \sum_i +\frac{d(\Delta p^{\nu}_{\mathrm{Q}_i})}{dt} G(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{Q}_i})$$

Set up of the simulation

initial jet parton → gluon

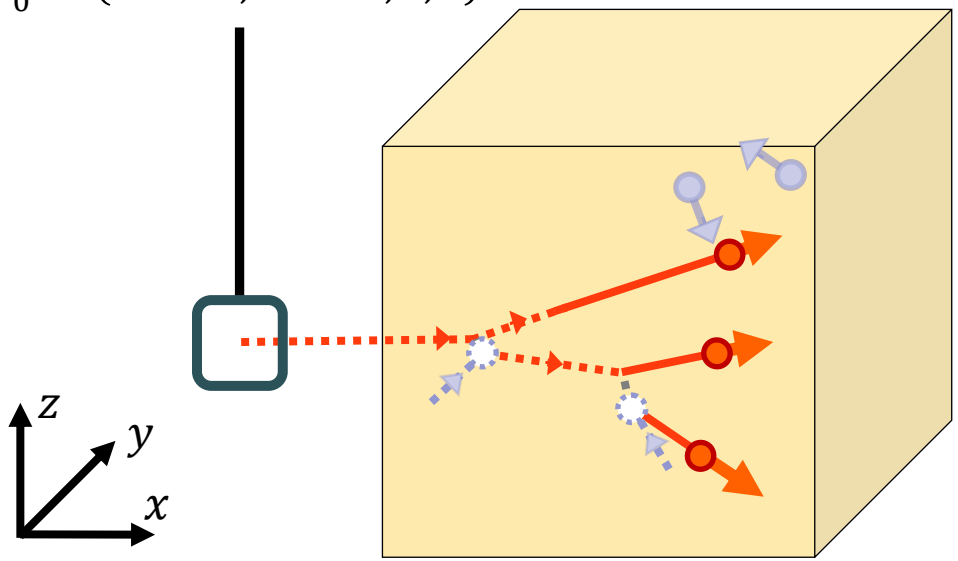
$\boldsymbol{x_0} = (0, 0, 0)$

$p_0^{\mu} = (50\ \mathrm{GeV}, 50\ \mathrm{GeV}, 0, 0)$

$T_0 = 500\ \mathrm{MeV}$

$\sigma_G = 0.3\ \mathrm{fm}$

$\alpha_s = 0.5$

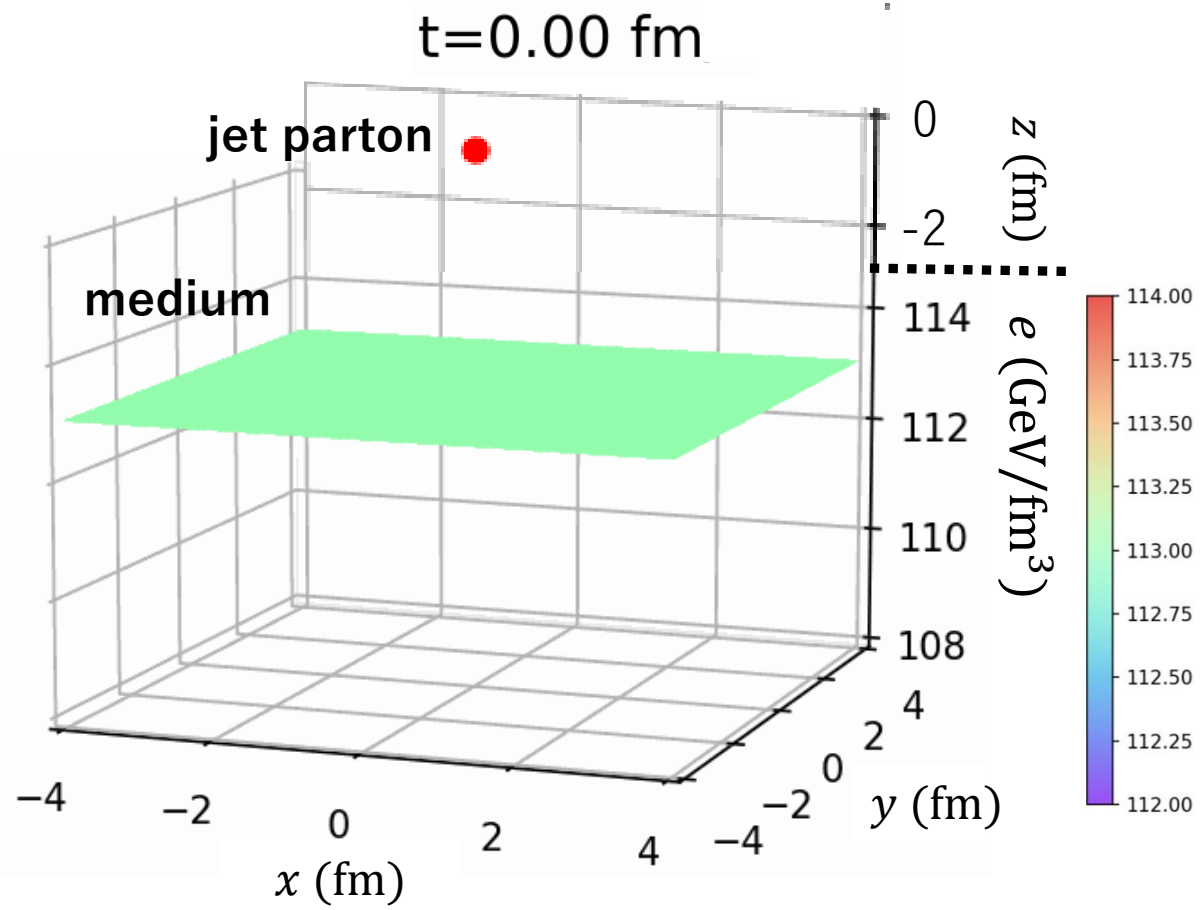


$@t = 2.0\ \mathrm{fm}$

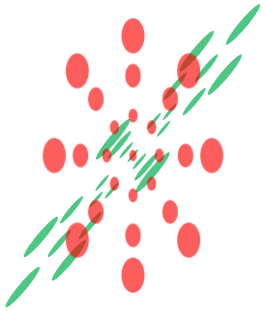
Particlized by Cooper-Frye formula at “parton level”

F. Cooper and G. Frye, Phys. Rev. D **10**, 186 (1974)

Time evolution of e_{QGP} with jet parton



Results



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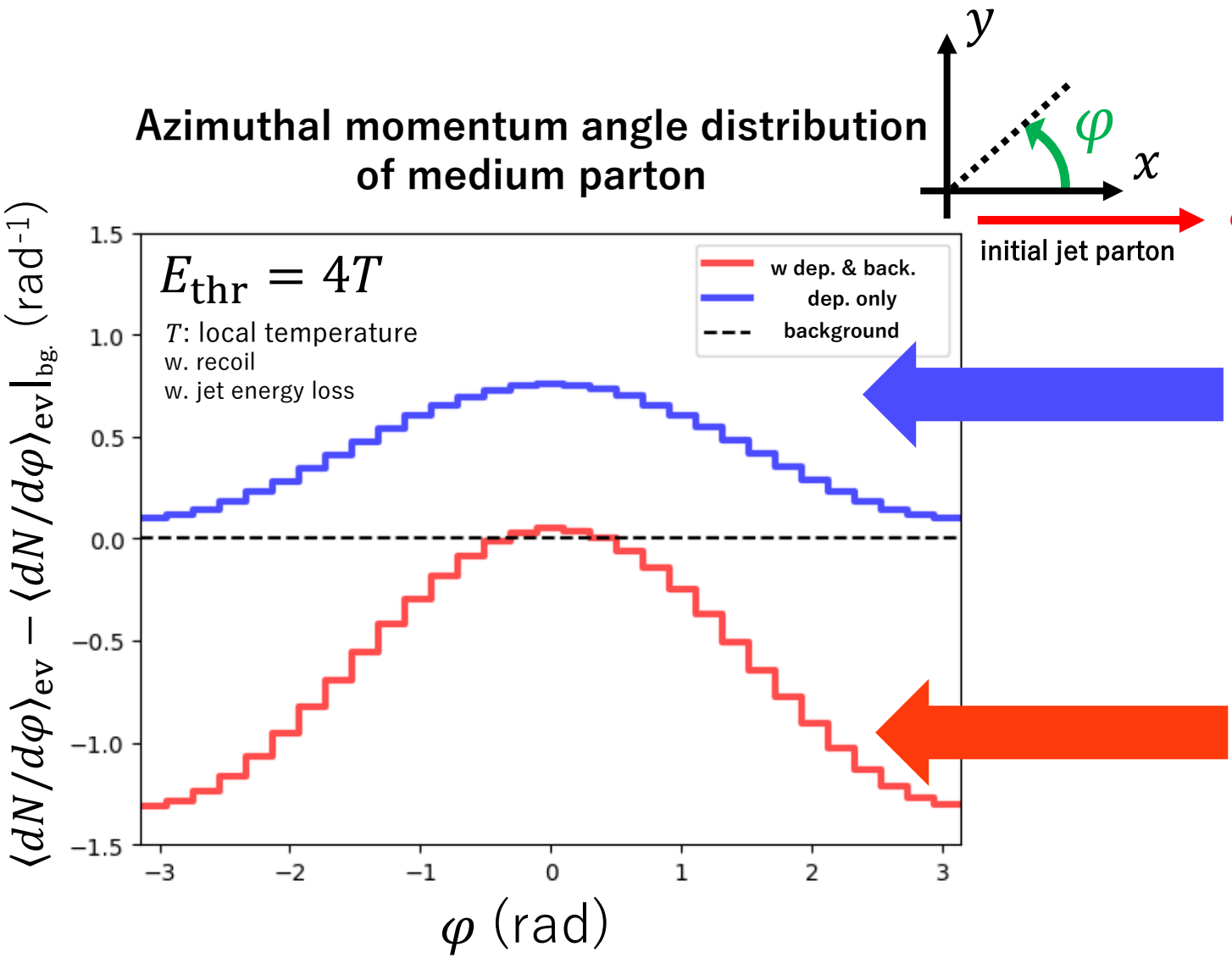
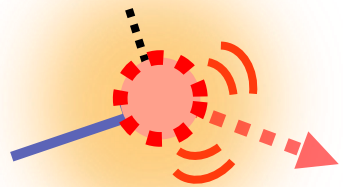
Effect of backreaction

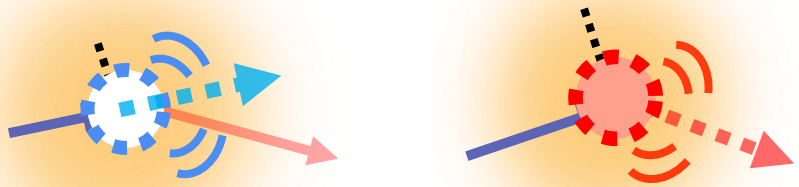
Azimuthal momentum angle distribution of medium parton



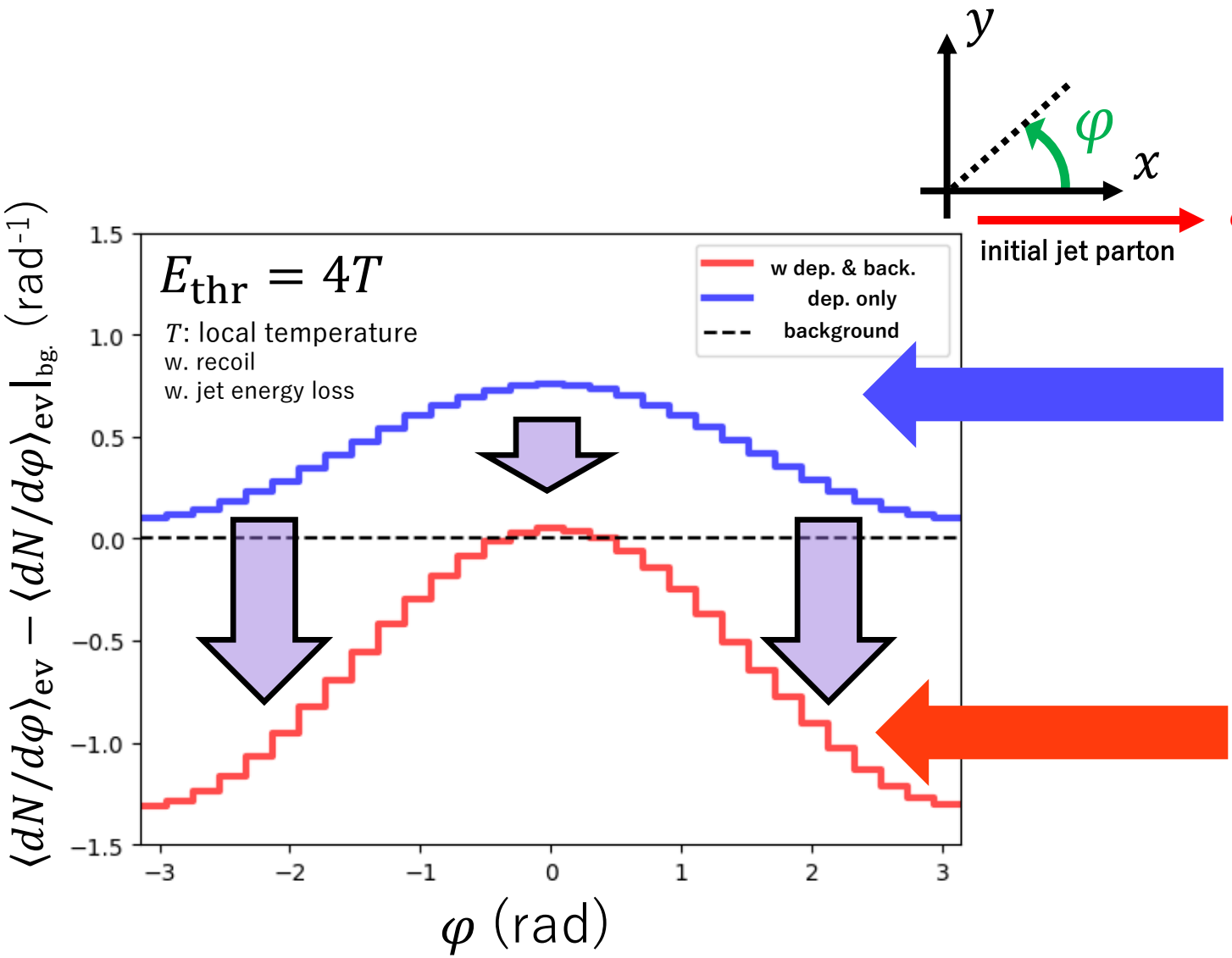
deposition only



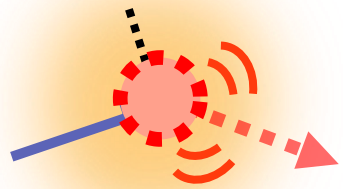
backreaction & deposition



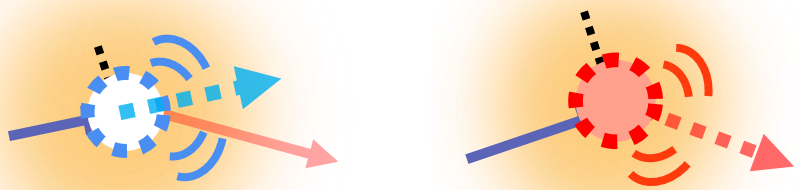
Effect of backreaction



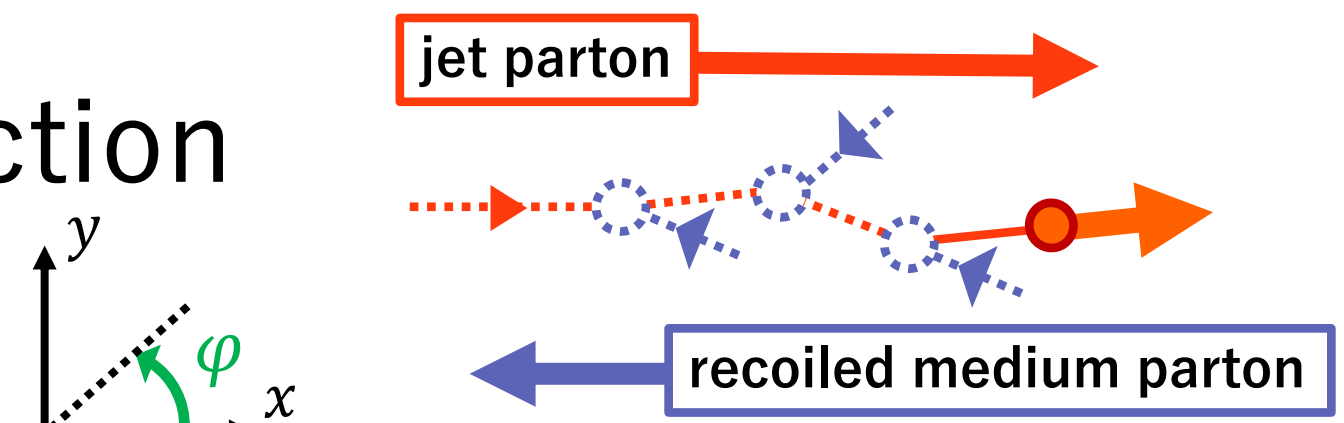
deposition only



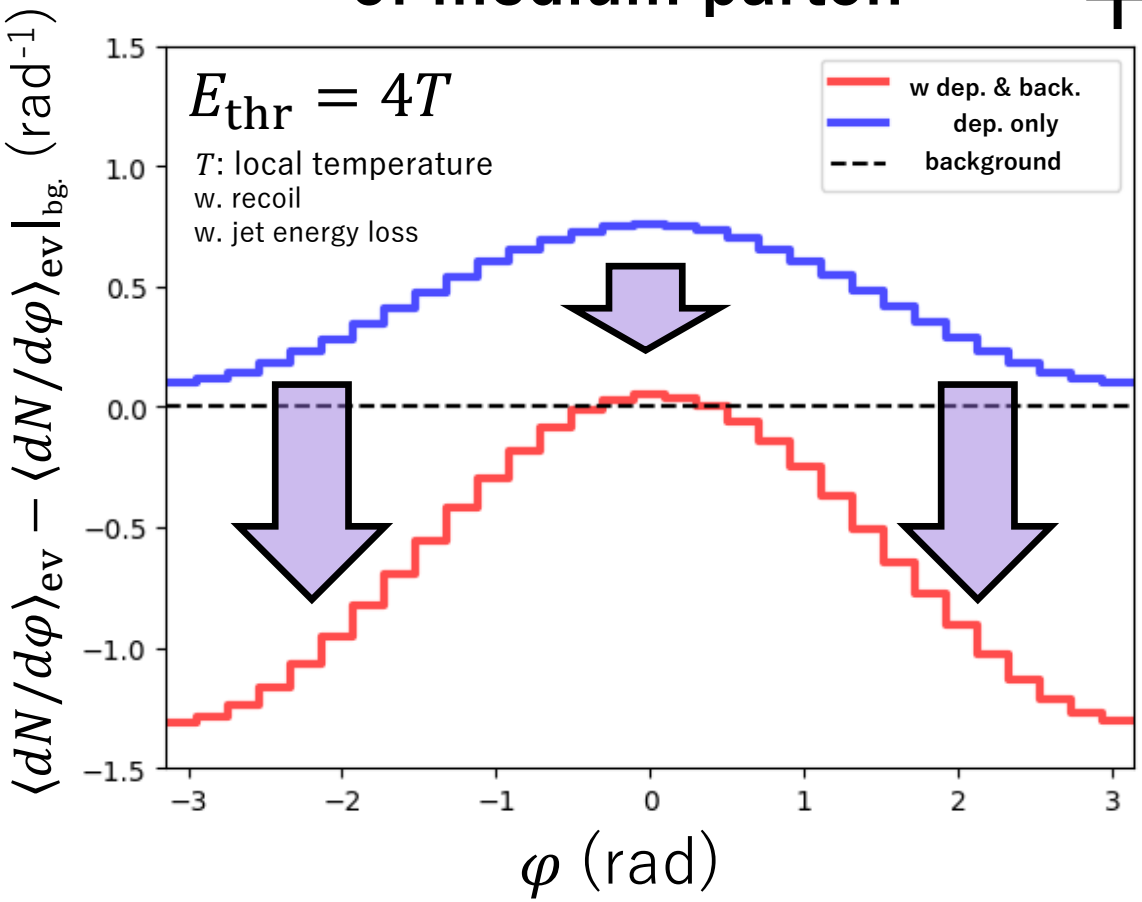
backreaction & deposition

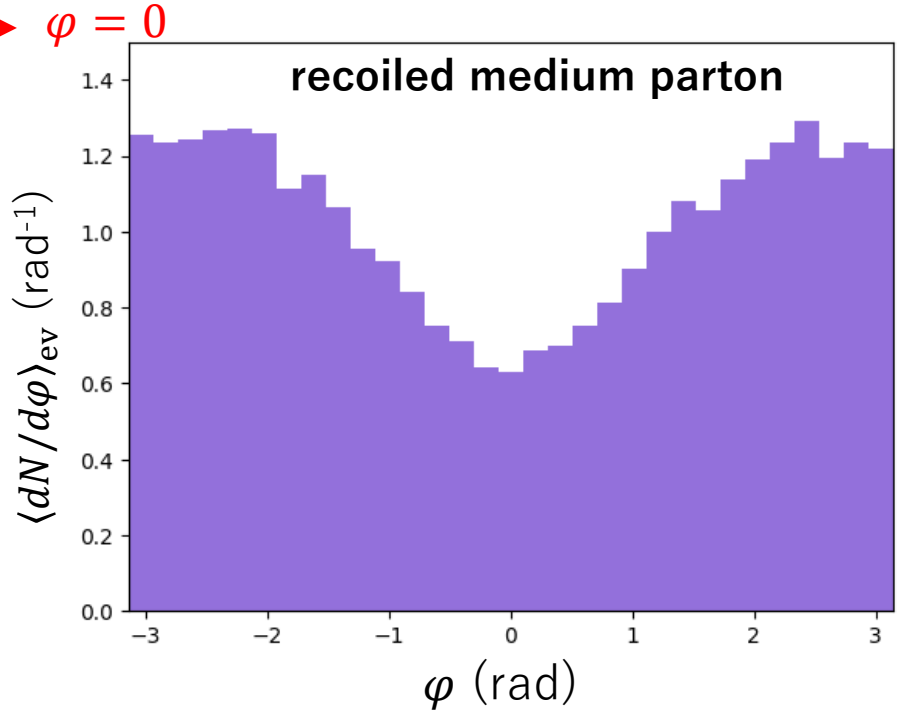


Effect of backreaction



Azimuthal angle distribution of medium parton

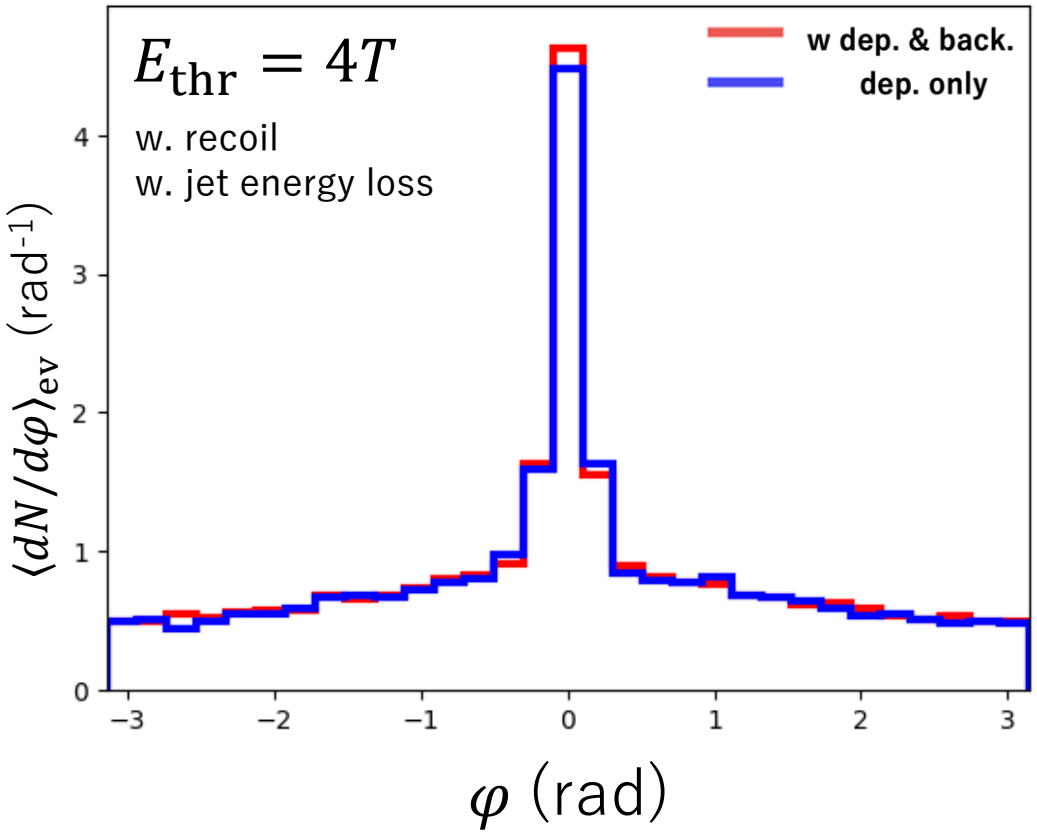




Scattering dynamics is crucial to backreaction

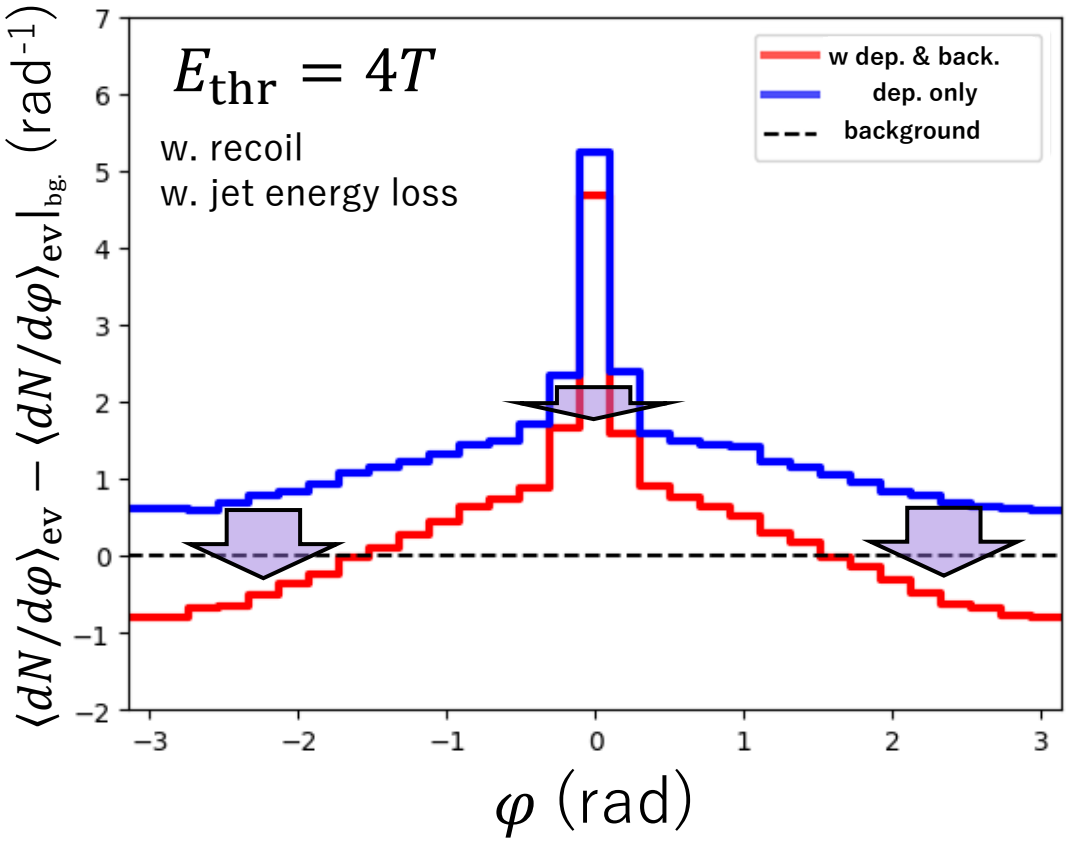
Effect of backreaction

jet parton



■ No significant effect by backreaction

total（jet parton + medium paton）

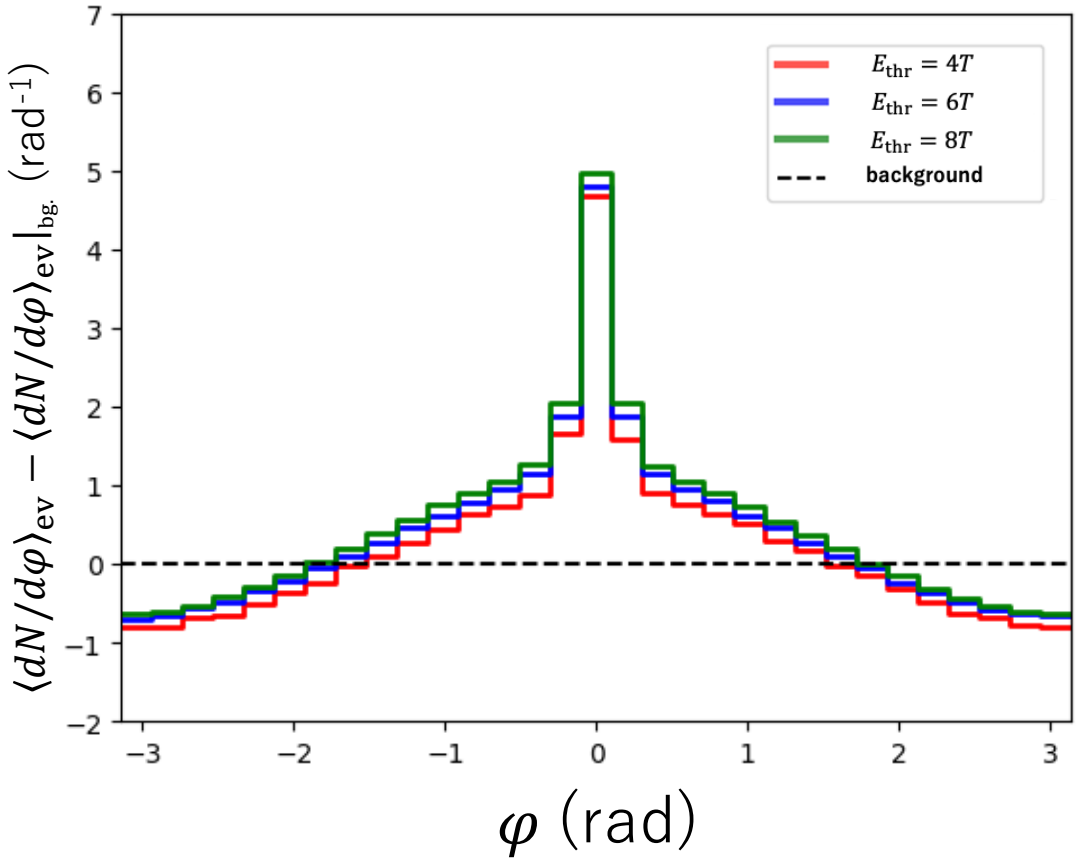


■ Backreaction modifies total $dN/d\varphi$

Interplay between backreaction vs deposition

$E_{\mathrm{thr}} = 4T, 6T, 8T$ T: local temperature

total（jet parton + medium parton）



Interplay between backreaction vs deposition

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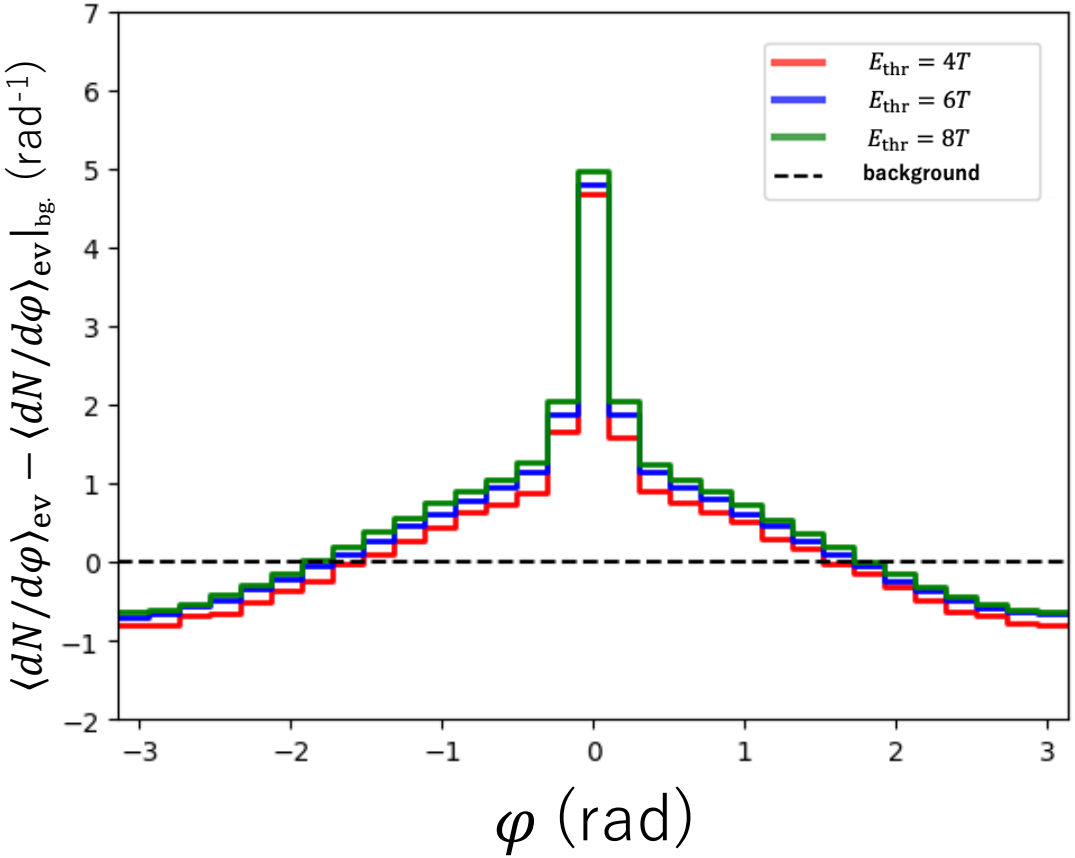
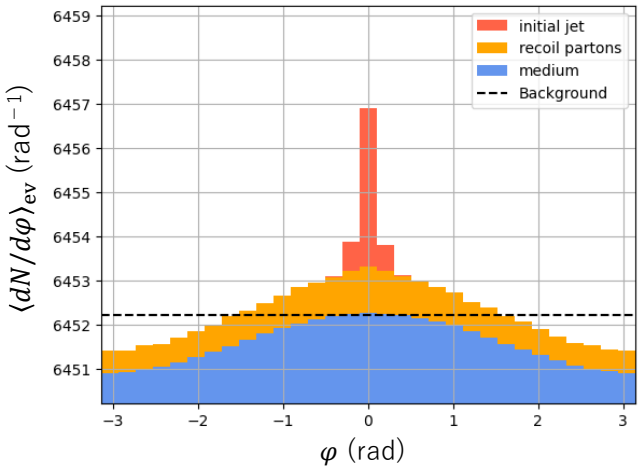


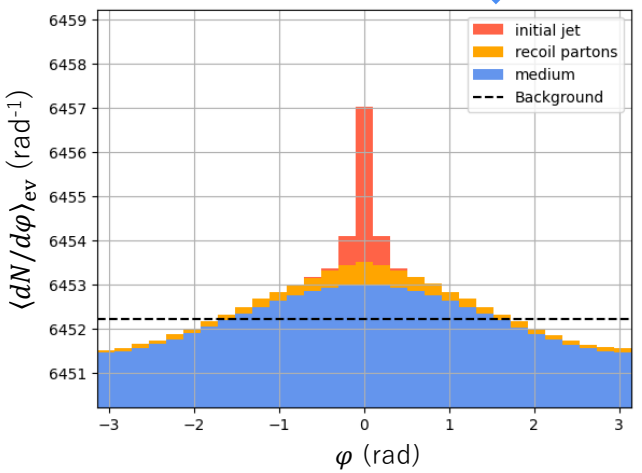
$E_{\mathrm{thr}} = 4T$

recoil & backreaction



$E_{\mathrm{thr}} = 8T$

recoil & backreaction

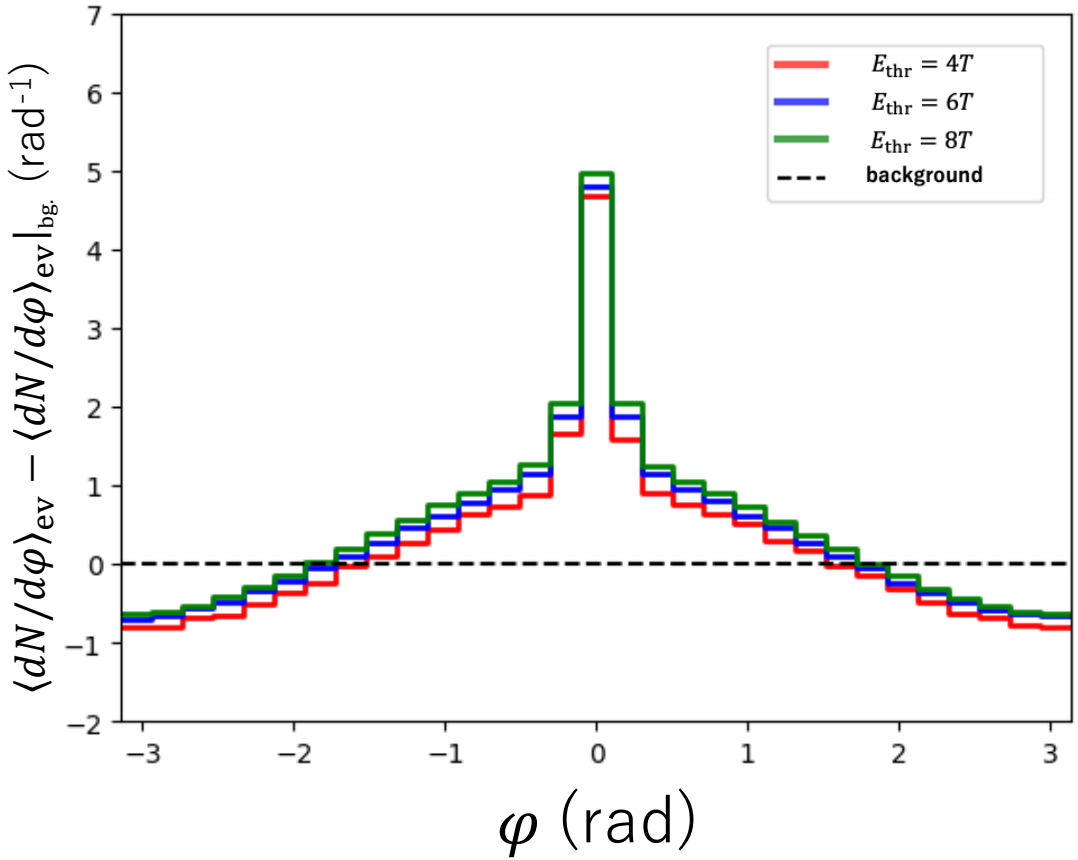


Different particle ratio of jet parton to medium parton

Interplay between backreaction vs deposition

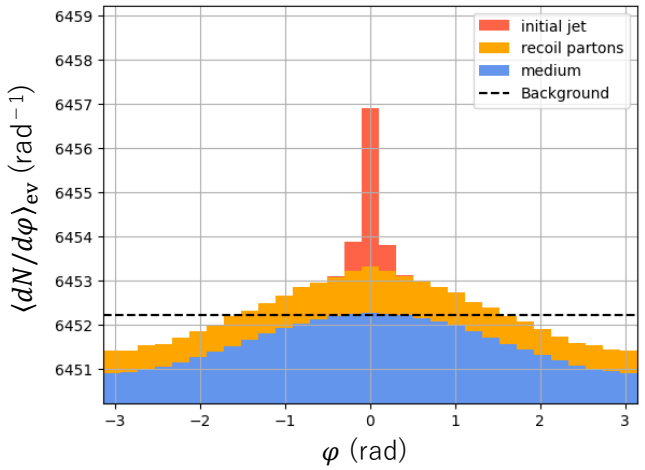
$E_{\mathrm{thr}} = 4T, 6T, 8T$ T: local temperature

total（jet parton + medium parton）



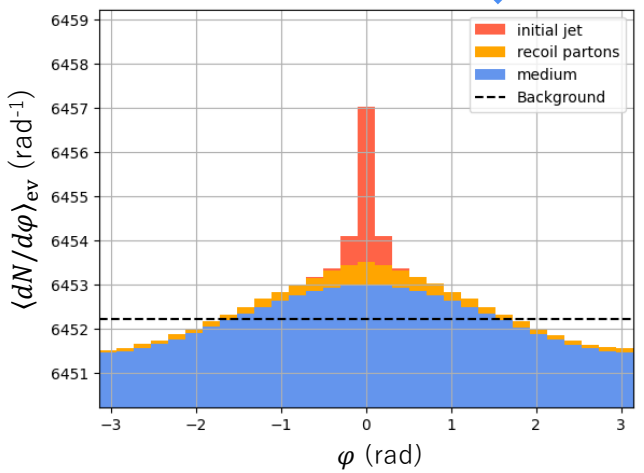
$E_{\mathrm{thr}} = 4T$

recoil & backreaction



$E_{\mathrm{thr}} = 8T$

recoil & backreaction



Different particle ratio of jet parton to medium parton

Jet: scattering fragmentation **VS** **medium:** $f_{\mathrm{eq}}(p, T)$

Different particle ratio of parton & hadron

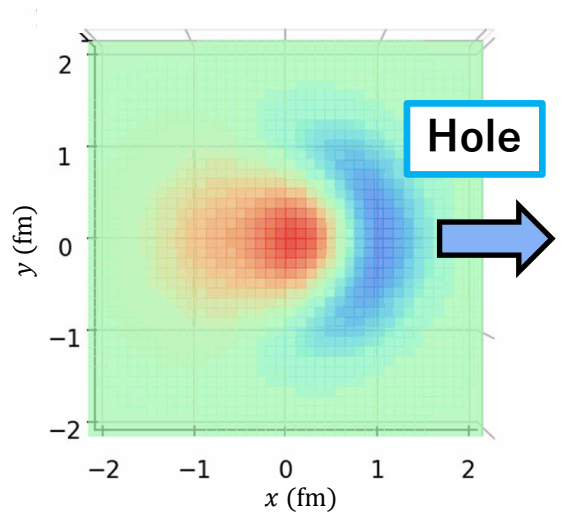
Outlook:
Investigate the particle ratio of hadron to constrain the backreaction picture

Summary and outlook

- We introduced hydrodynamic equation with “negative” source term to describe the backreaction of QGP dynamically

- Movement of hole and wake behind the hole
- Scattering dynamics is crucial to backreaction

  ➡ Modifies $dN/d\varphi$ of medium partons



Outlook

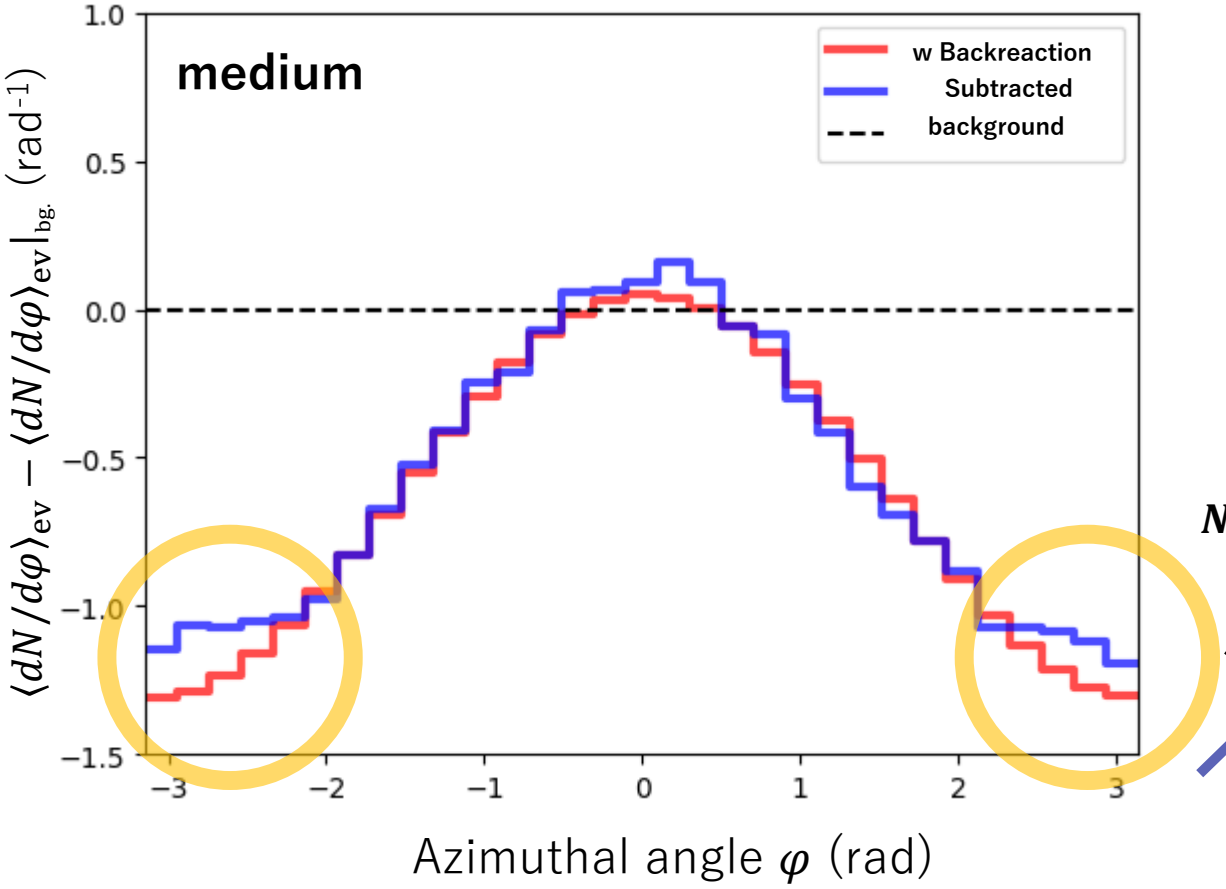
- Use PYTHIA for initial jet partons & analyze the jet structure function
- Include backreaction to Dynamical Core-Corona Initialization (DCCI) to compare with experiment

Y. Kanakubo *et al.*, Phys. Rev. C **105** , 024905 (2022)

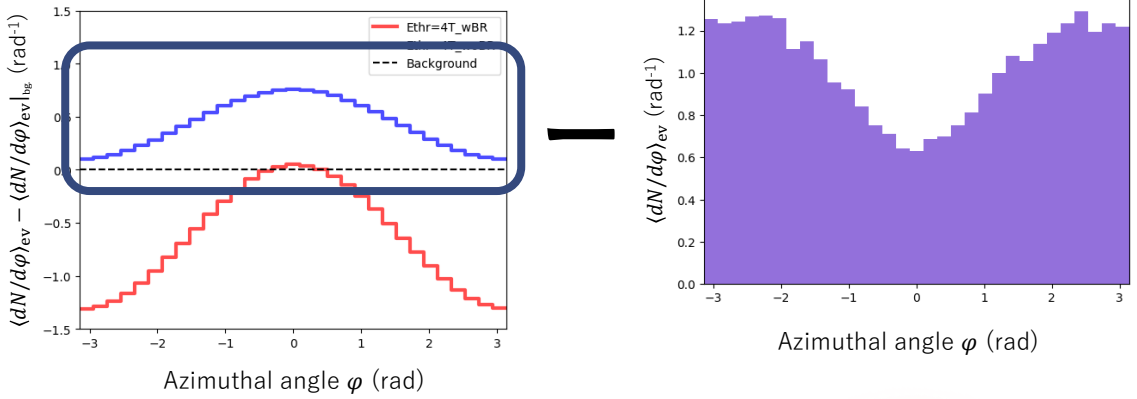
Back up

Dynamical hole effect

Azimuthal angle distribution



Subtracted
= only deposition − recoiled medium parton



$N_{1\,\mathrm{hole}} = -1$ $\neq$ $N_{1\,\mathrm{hole}} \neq -1$

interference of holes?

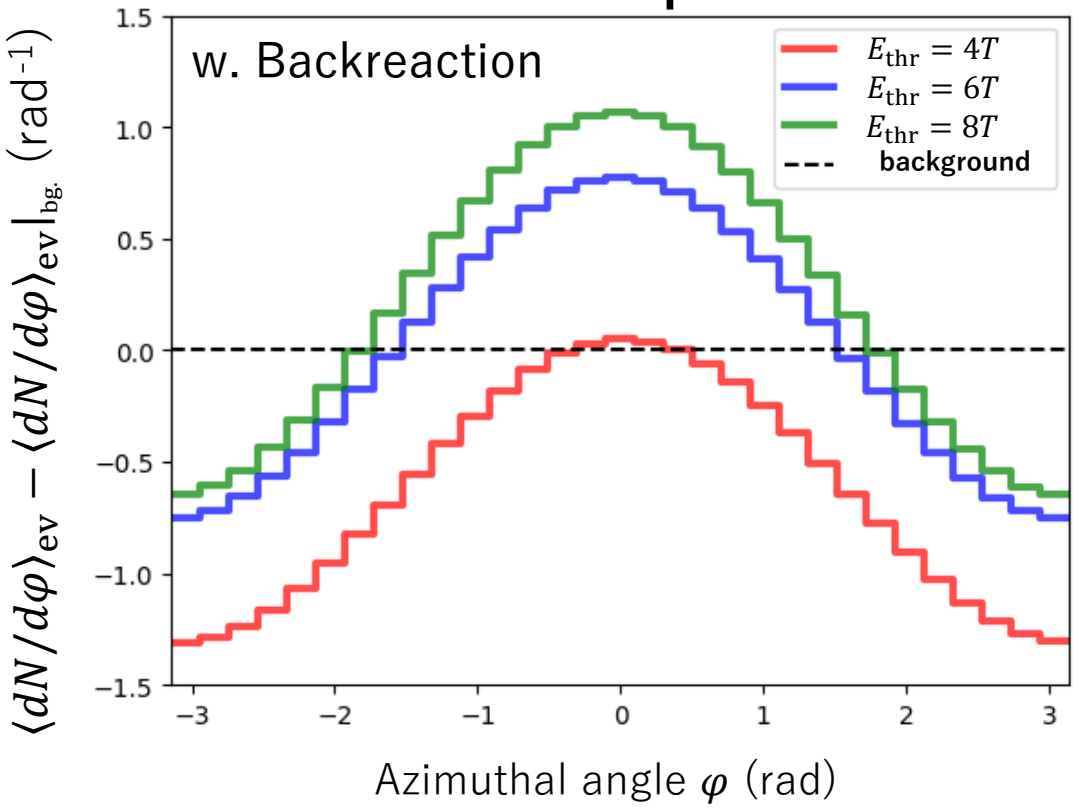
→more analysis is necessary

Threshold of recoil $E_{\mathrm{thr}} = 4T, 6T, 8T$

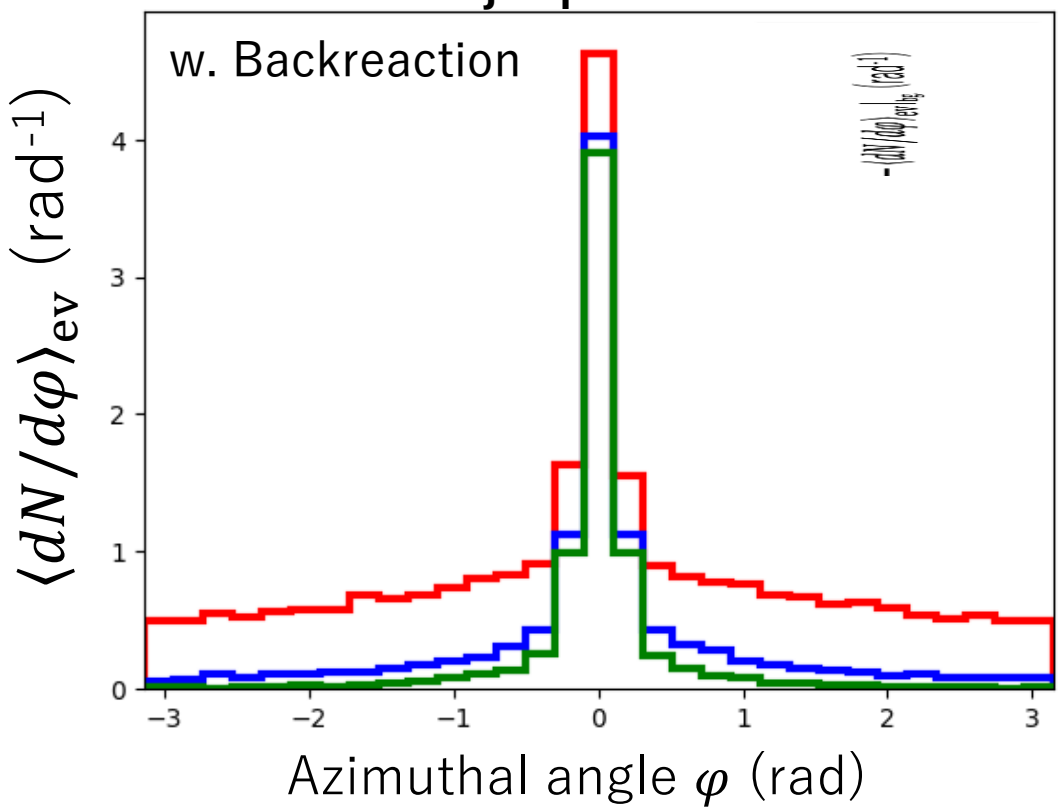
Setting: $T_0 = 500\ \mathrm{MeV}, \mathrm{type}_0 = g,\ p_0^\mu = (50\ \mathrm{GeV},\ 50\ \mathrm{GeV},\ 0,\ 0),\ t_{\mathrm{sw}}, = 2.0\ \mathrm{fm/c}\ \ 5000\ \mathrm{events}$

w. **energy loss**, w. **deposition**, w. **recoil**

medium partons



jet partons



E_{thr} ↑ → the effect of deposition ↑, backreaction ↓