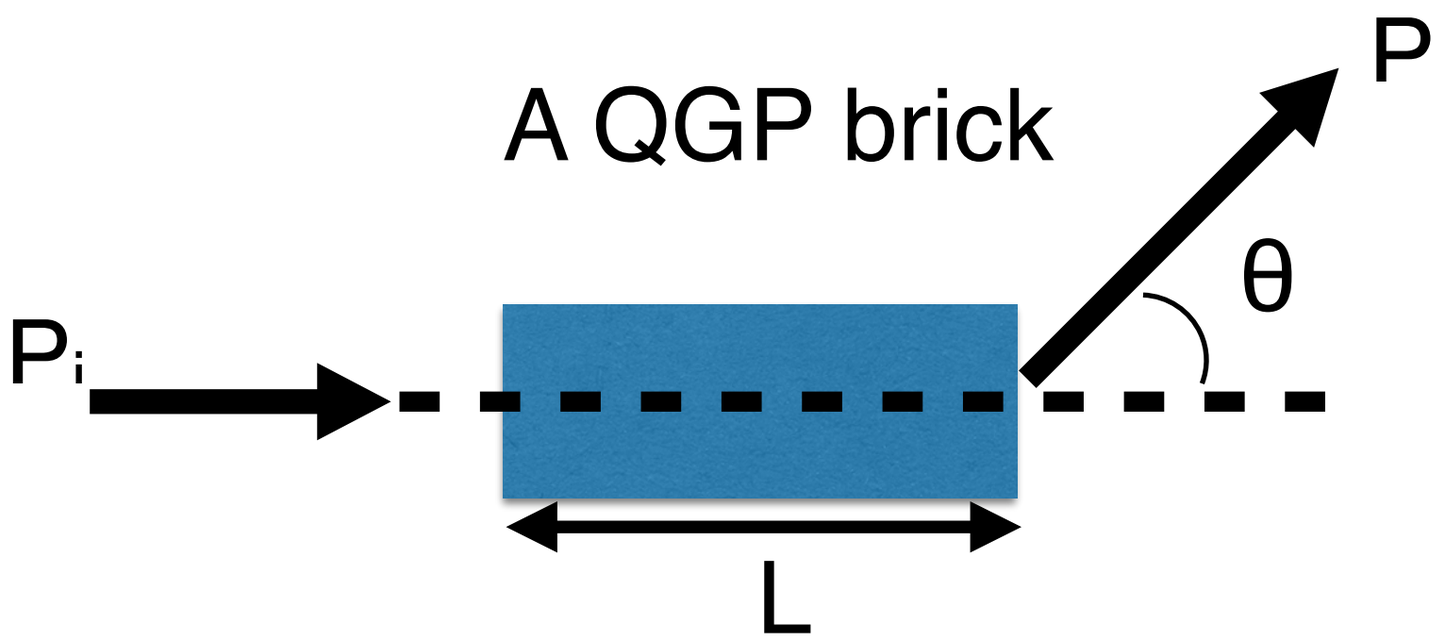
Resolving Point-Like Scatterers in a Liquid QGP



Based on: F. D'Eramo, K. Rajagopal and YY, 1808.03250 (JHEP, to be published) . See 1812.06878 for a shorter version

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JETSCAPE Workshop, Jan.11, 2019

Background

Last decade has seen significant progress on understanding the *long distance* behavior of quarks and gluons in QGP.

Next?

Beam energy scan: the evolution of QCD matter as a function of baryon density.

Jet physics at HIC: resolve quarks and gluons in a QGP, and study the evolution of their properties as a function of resolution scale.

EIC (US, EU, China): resolve quarks and gluons in a proton, and study the evolution of their properties as a function of resolution scale.

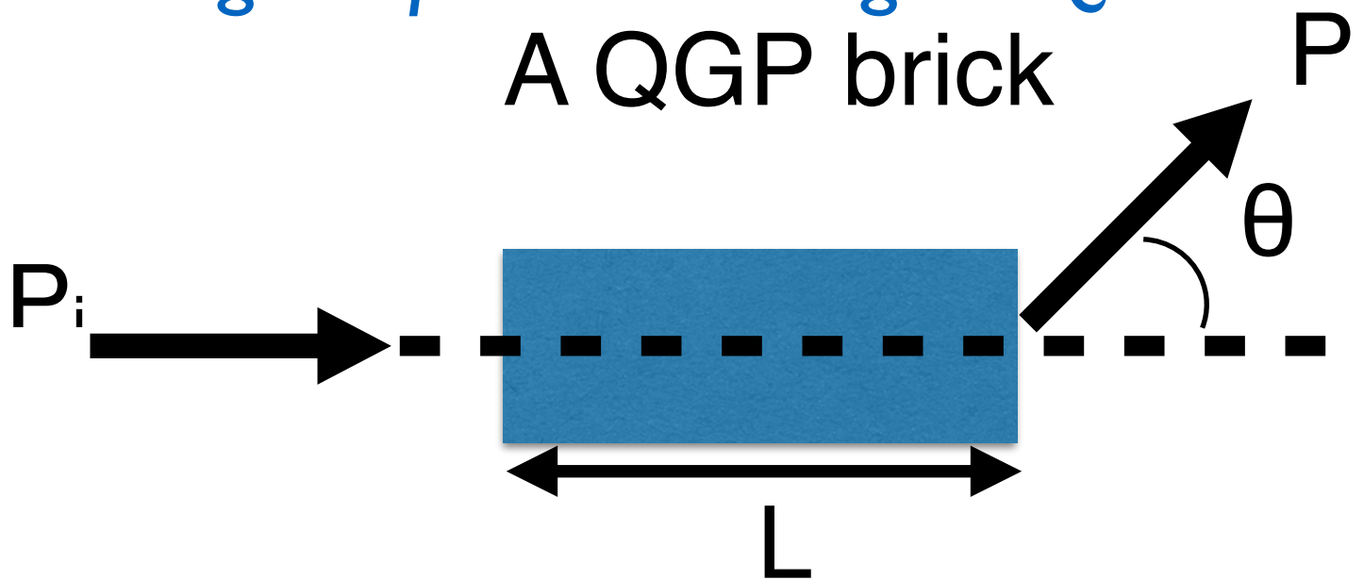
The keyword about the future: evolution

This talk: resolve the individual quarks and gluons in QGP? (via a single scattering with large energy/momentum transfer)

Challenges: sophisticated modeling v.s. precision measurements.

This talk: providing a key theoretical input for future phenomenological analysis.

Shooting an energetic parton through a QGP brick



The object of study: (phase space) distribution of outgoing parton: F(p,θ).

Our goal: evaluate F(p, θ) due to a single binary scattering. (see also related study via LBT model.)

Providing inputs for future quantitative studies.

Estimating the threshold angle above which a single scattering becomes dominant and how rare a large angle scattering is.

incident parton + **QGP scatterer** → **outgoing parton** + X

$$F(p,\theta) = L \sum_{\textbf{processes}} \int_{k_{\text{scatterer}}} |\mathscr{M}(s,t)|^2 \, n(k_{\text{scatterer}})$$

The quantity in analogue to F(p,θ) has been studies previously in the regime

$$p_i/T \to \infty\,, \quad \frac{gT}{p_i} \ll \theta \ll 1$$

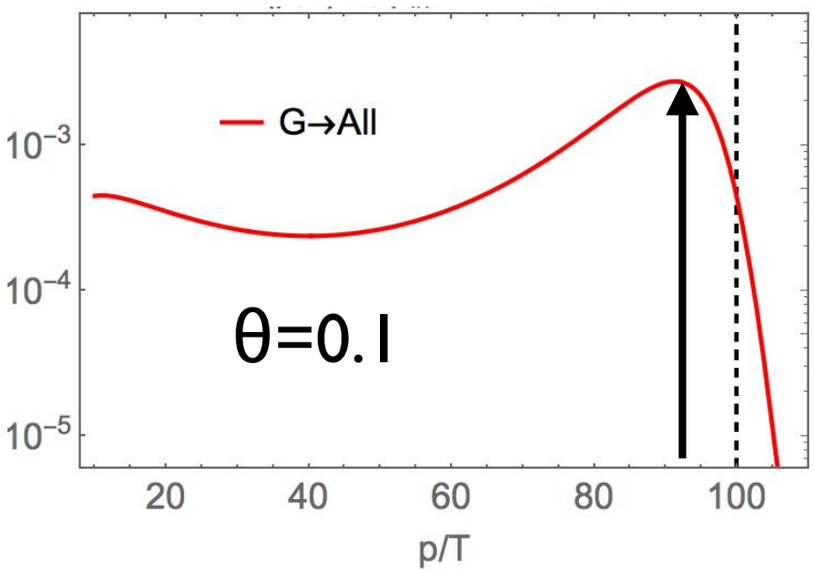
e.g. Aurenche, Gelis and Zaraket JHEP '02; Arnold-Dogan PRD '08; D'Eramo, Lekaveckas , Liu, Rajagopal, JHEP '12…

Our work: p_i/T is large but not infinity + θ **can be** $\mathcal{O}(1)$.

In different kinematic regime, the relative importance among different processes changes.

As a consequence, new feature emerges!

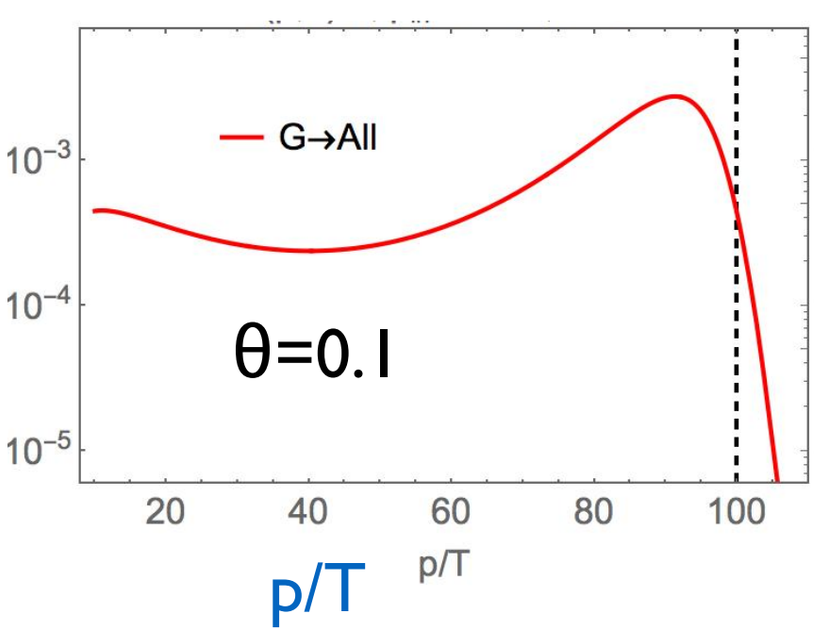
Shooting a gluon with initial energy p_{in}=100T

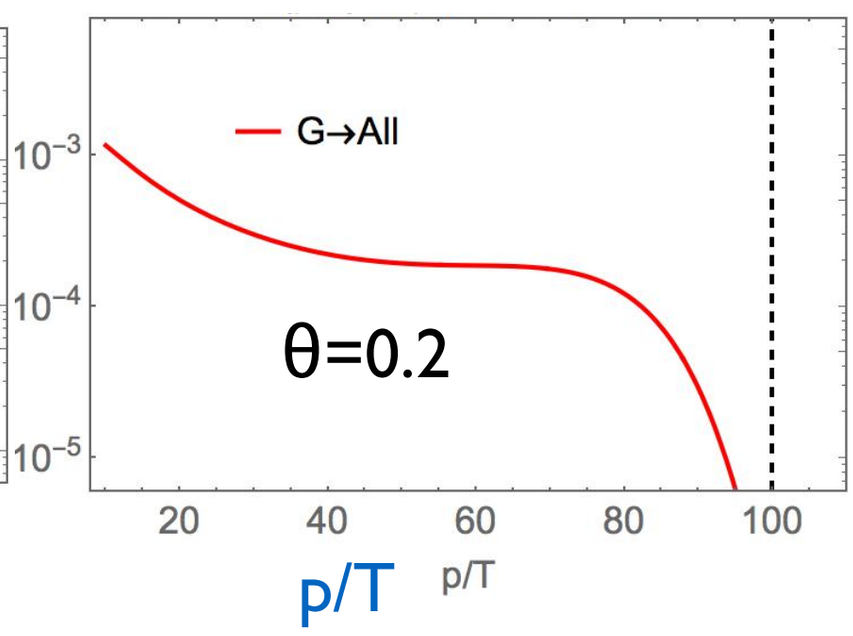


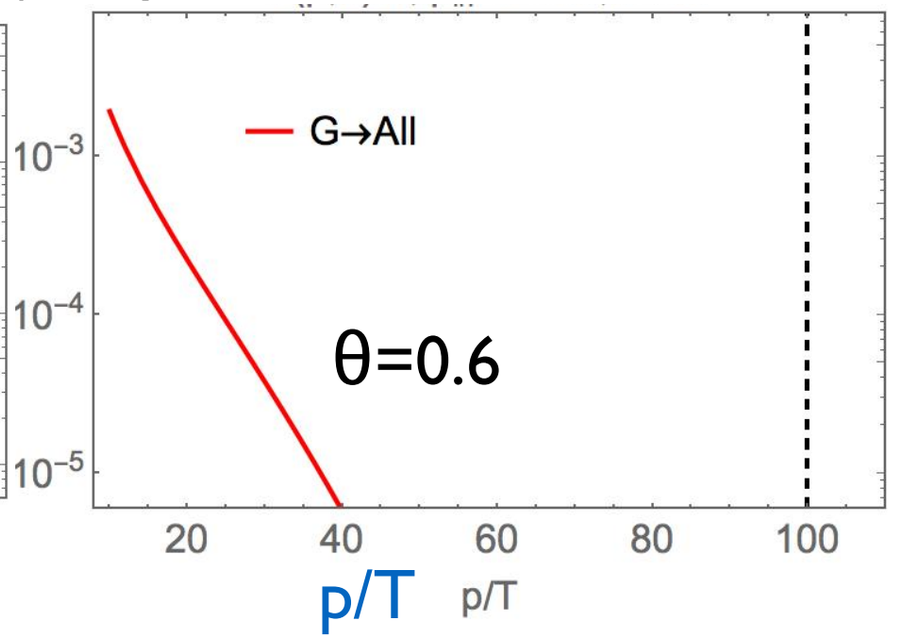
F(p,θ)/(g^4LT) vs p/T for different θ s

Shooting a gluon with initial energy p_{in}=100T

$F(p,\theta)/(g^4LT)$ vs p/T for different θ s

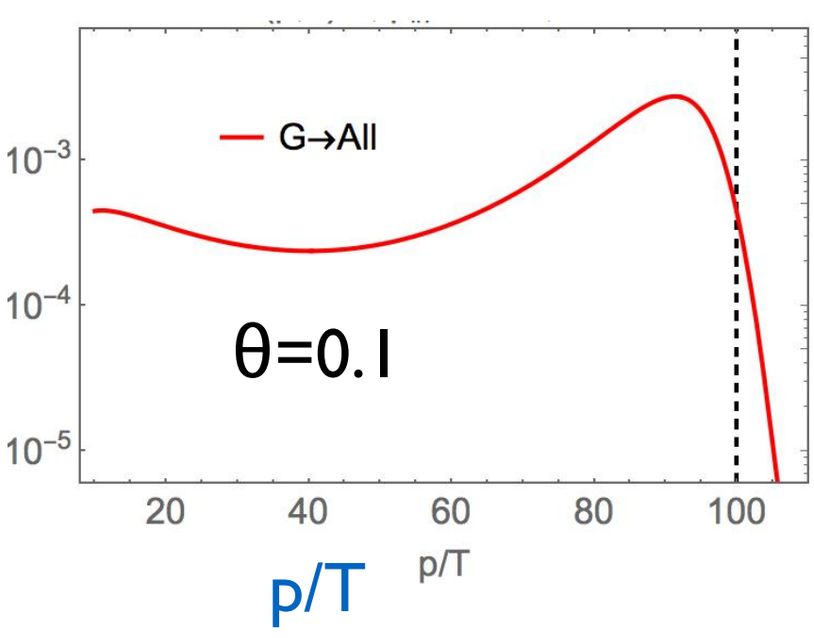


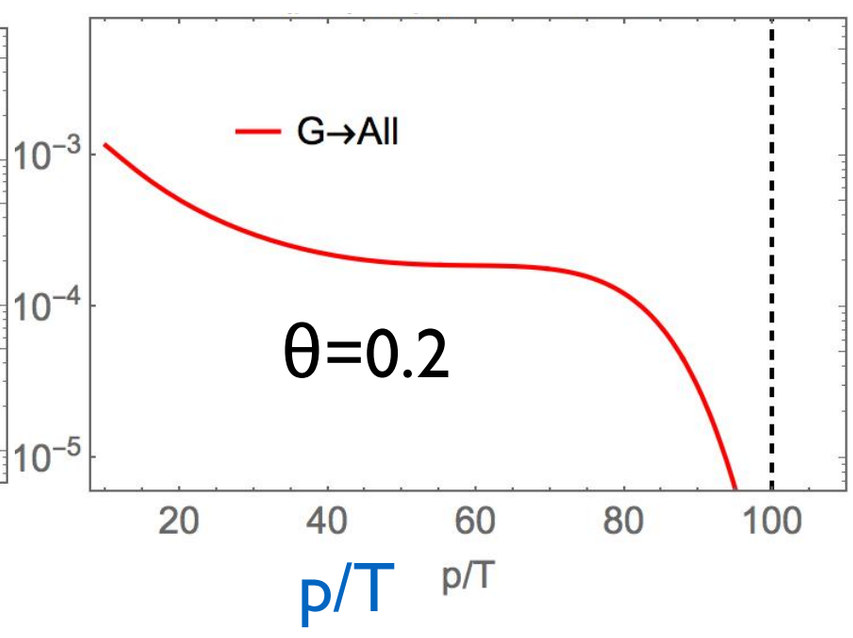


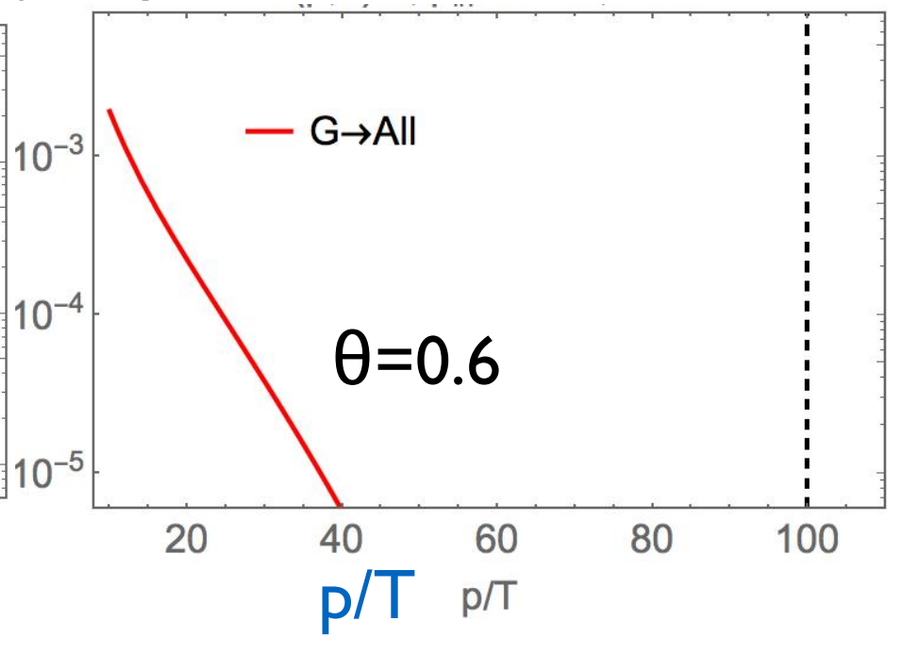


Shooting a gluon with initial energy p_{in}=100T

F(p,θ)/(g⁴LT) vs p/T for different θ s





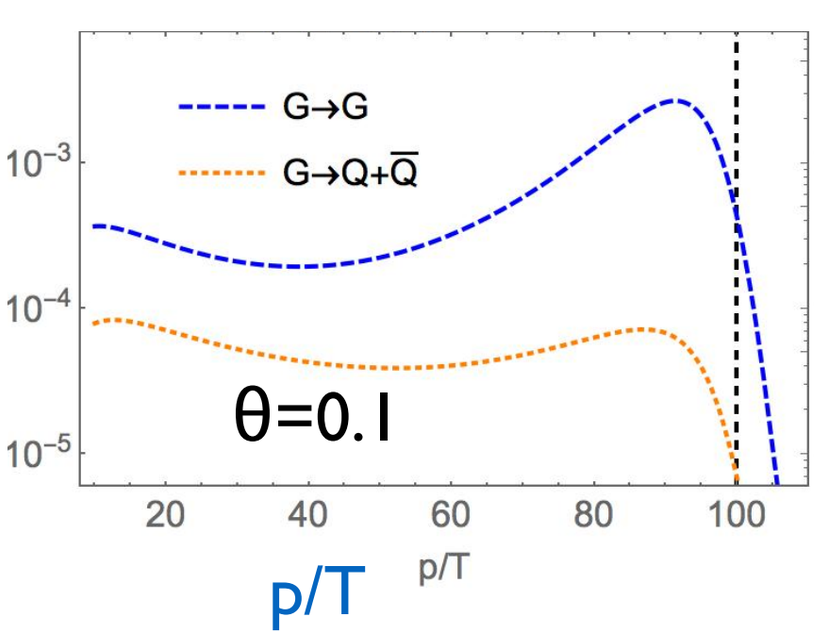


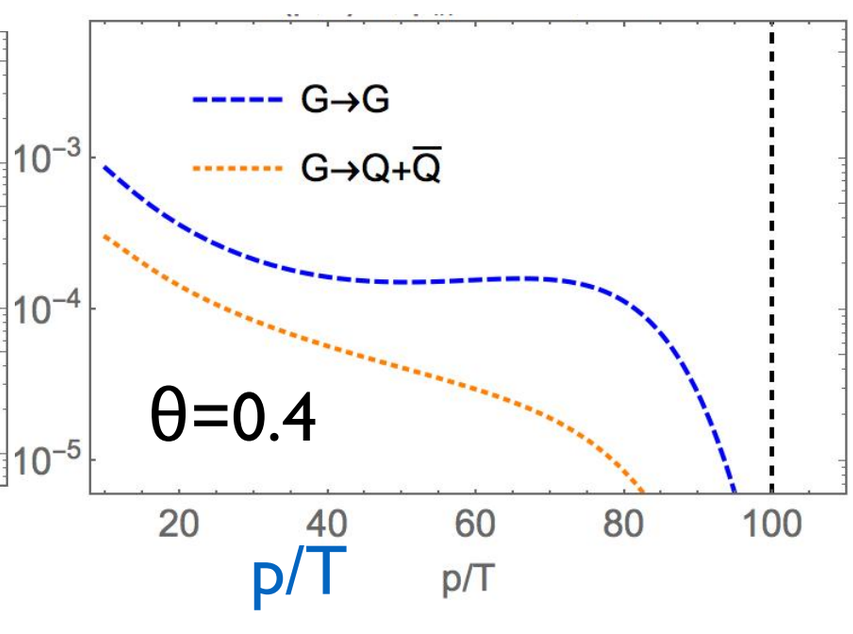
Qualitative changes on p-dependence with increasing θ.

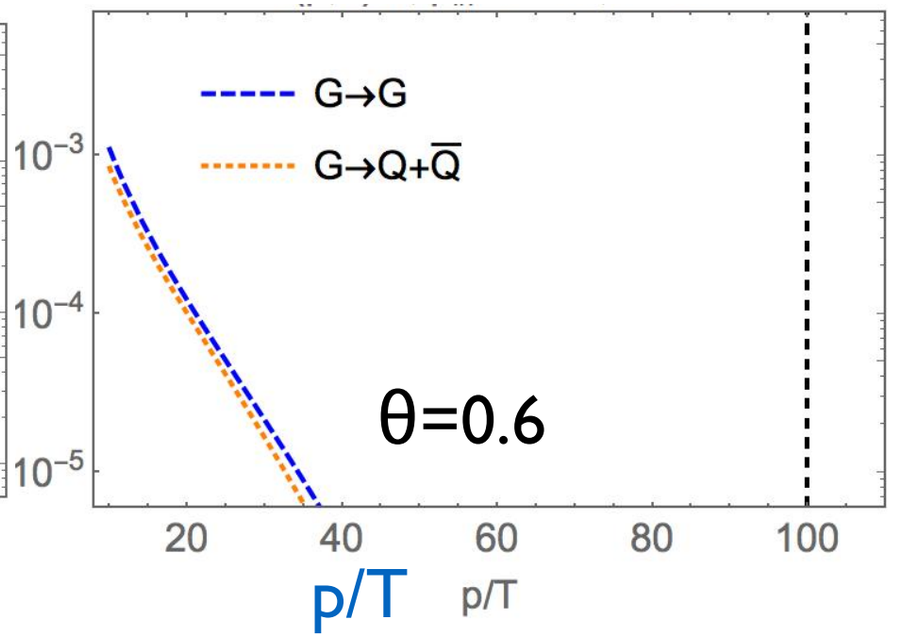
Kinematic constraint: large momentum transfer requires large energy transfer.

At large angle, more outgoing partons are coming from the scatterers in the QGP brick. (Related to this, processes such as $gg \longrightarrow q\bar{q}$ can be as important as "Rutherford scattering", e.g. $gg \longrightarrow gg$)

Distribution of outgoing gluon and quark. $F(p,\theta)/(g^4LT)$ vs p/T for different θs





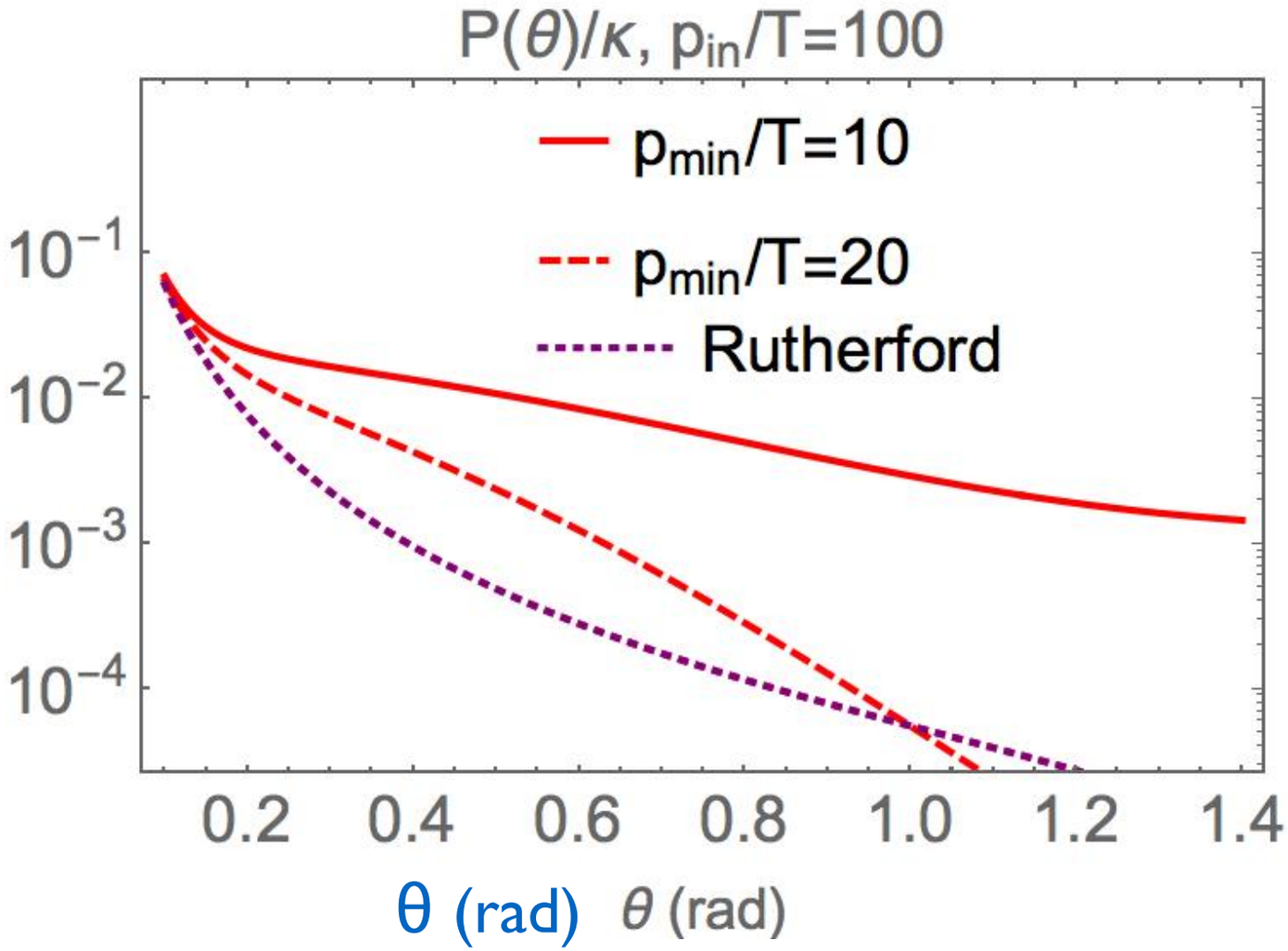


With increasing θ, the number of outgoing quark becomes comparable to that of outgoing gluon.

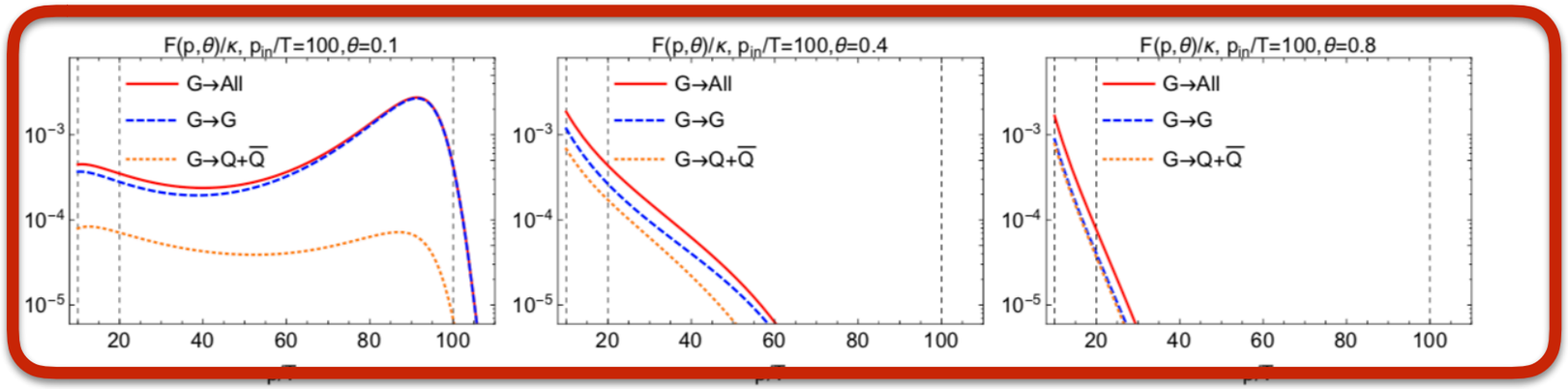
As more partons are coming from the medium, outgoing parton at large θ carries more information about the medium itself.

Angle distribution

$$P(\theta) \equiv \int_{p_{\min}} dpF(p,\theta)$$



(An incident gluon with initial energy p_i =100T.)



For results with other values of p_i/T and the case with an incident quark, see our paper (we are happy to provide tabulated results as well).

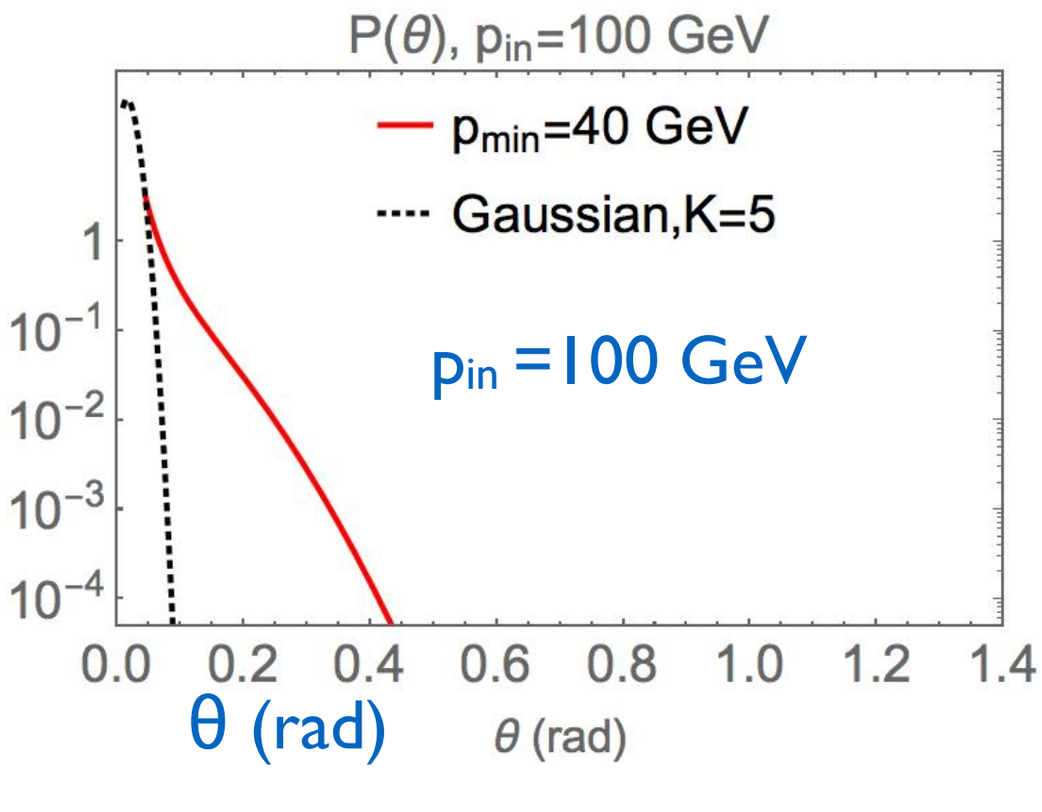
Q1: above which θ a single scattering is dominant over the results from multi-scatterings. ?

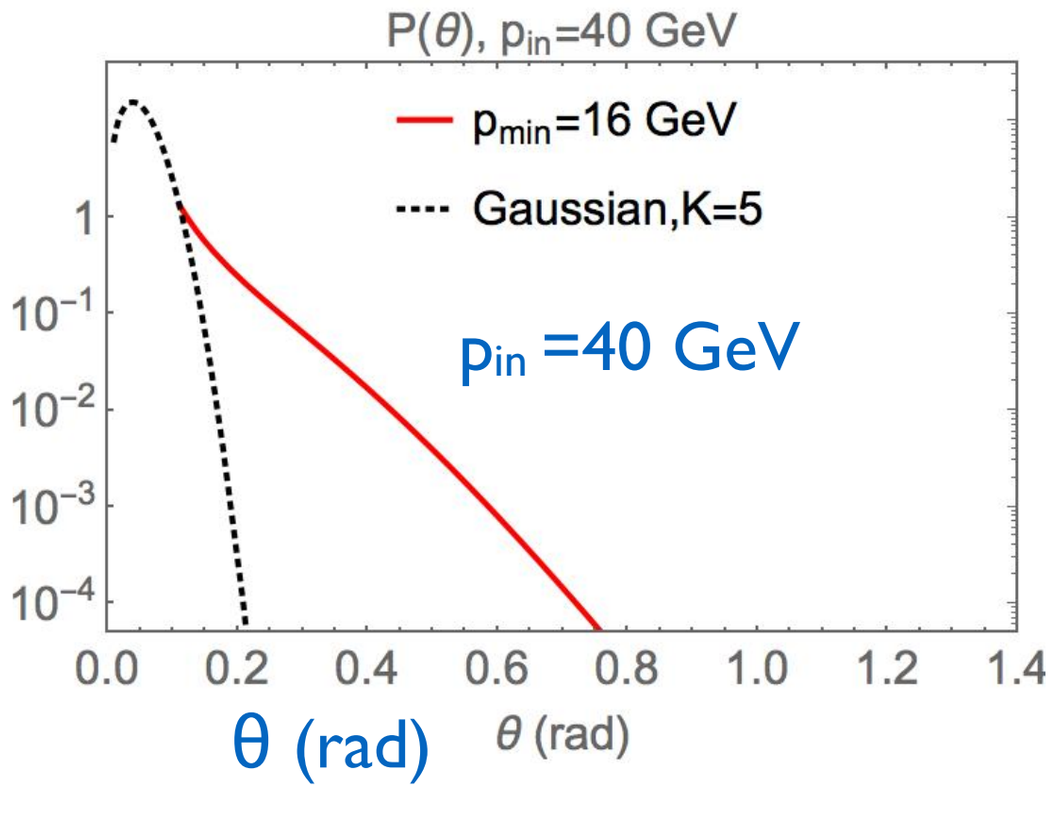
c.f. Kurkela and Wiedemann, PLB '14

Q2: In the single scattering dominant regime, how rare a single scattering will happen?

From now on: g=1.5, T=0.4 GeV, L=3fm

Above which θ a single scattering becomes dominant?

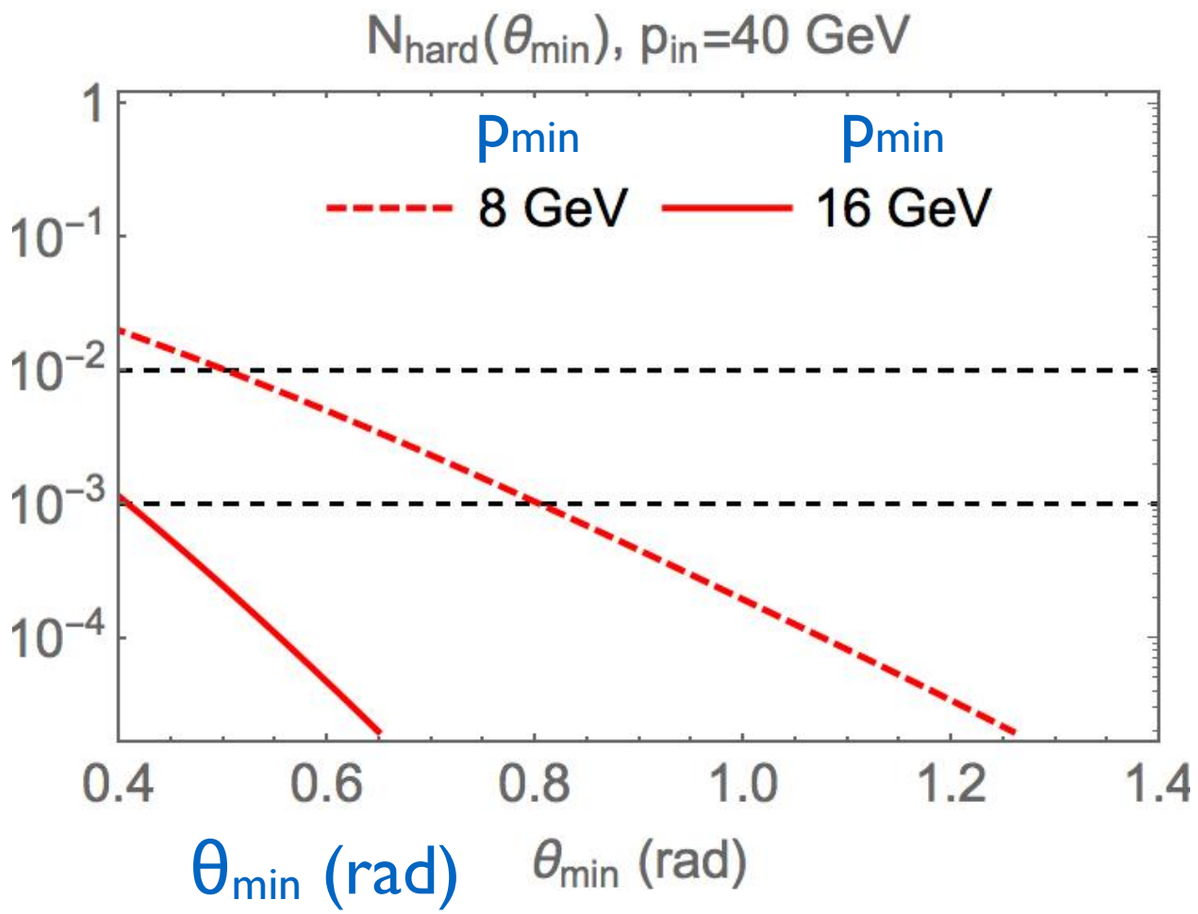




We make the comparison between our results and Gaussian distribution. (We relate the width of Gaussian to jet-quenching parameter.)

Choosing a suitable p_i is helpful for looking for large angle scattering.

$$N_{\text{hard}}(\theta_{\text{min}}) \equiv \int_{\theta_{\text{min}}} d\theta\, P(\theta)$$



For example: for p_{min}=8GeV, N_{hard} = 0.01 for θ>0.5 and N_{hard} = 0.001 for θ>0.8.

Summary and outlook

We have evaluated the phase space distribution of an outgoing parton due to a single scattering between an energetic incident parton and the scatterers in QGP brick.

Processes different from Rutherford scattering can be important with large angle.

Future: from an energetic parton to a parton shower; from a QGP brick to the expanding fireball.

Personal perspective: short-distance does not mean that there will be no surprise.(e.g. the phases of large baryon density limit of QCD is rather rich). Look forward to surprises about short-distance behavior of quarks and gluons in QGP.

Back-up

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"*Extremely small objects and incredibly rapid processes are now being seen in a new light.*"

The announcement of Royal Swedish Academy of Sciences

It would be interesting if the "small objects" and "rapid processes" of hot QCD matter being seen.