MICROJET SPECTRUM AND INTRA-JET DISTRIBUTIONS IN HEAVY-ION COLLISIONS

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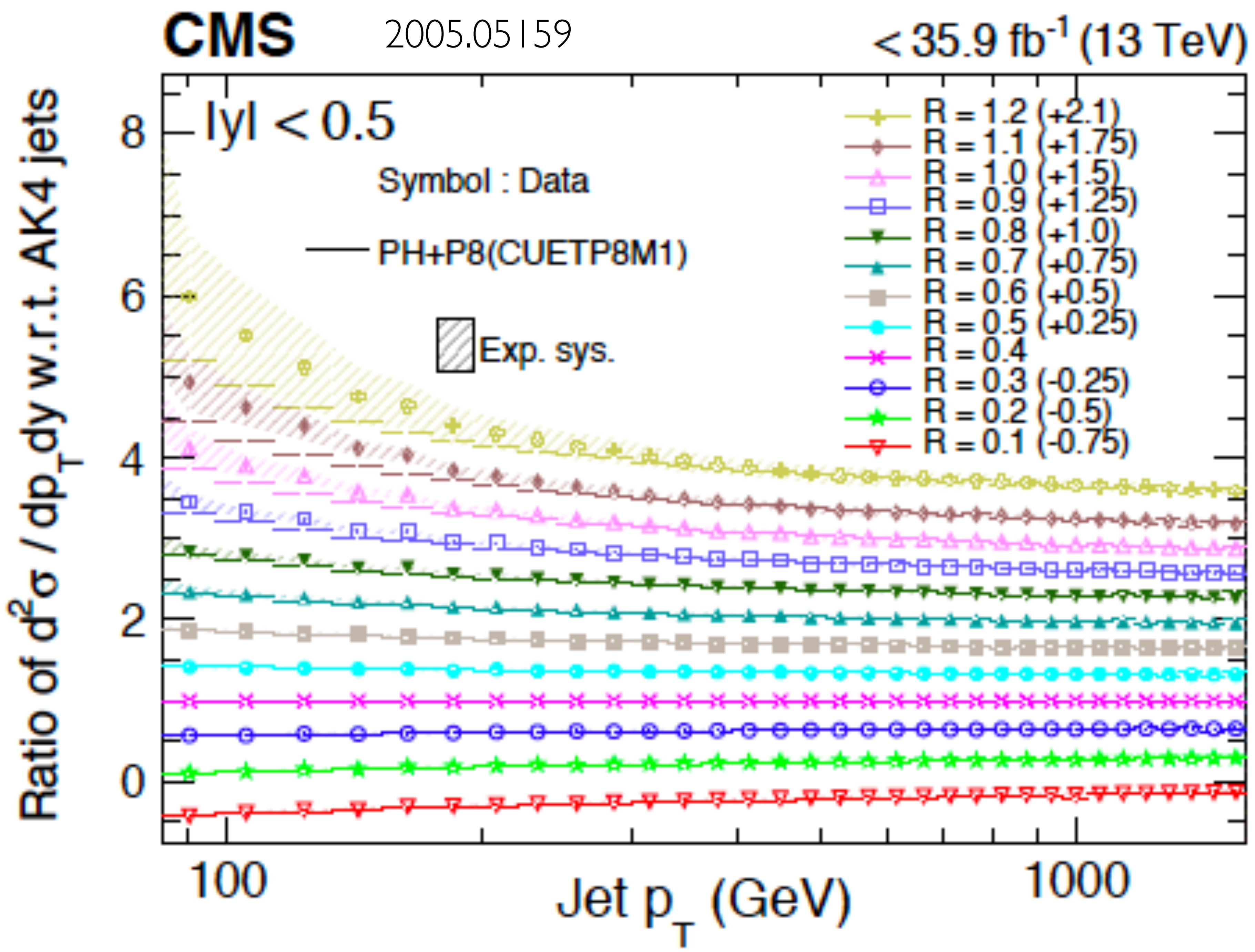
JET SPECTRUM AT HIGH-p_T

Aversa, Chiappetta, Greco, Guillet NPB1989
de Florian, Vogelsang 0704.1677
Dasgupta, Magnea, Salam 0712.3014

- Jets approximate partons created in hard scatterings
- Result in collimated sprays of particles



Out-of-cone radiation:

$$(\delta p_{\mathrm{T}})_q = -C_F \frac{\alpha_s p_T}{\pi} \log \frac{1}{R} \left(2 \log 2 - \frac{3}{8} \right)$$

$$(\delta p_{\mathrm{T}})_g = -\frac{\alpha_s p_{\mathrm{T}}}{\pi} \log \frac{1}{R} \left[C_A \left(2 \log 2 - \frac{43}{96} \right) + T_{\mathrm{R}} n_{\mathrm{f}} \frac{7}{48} \right]$$

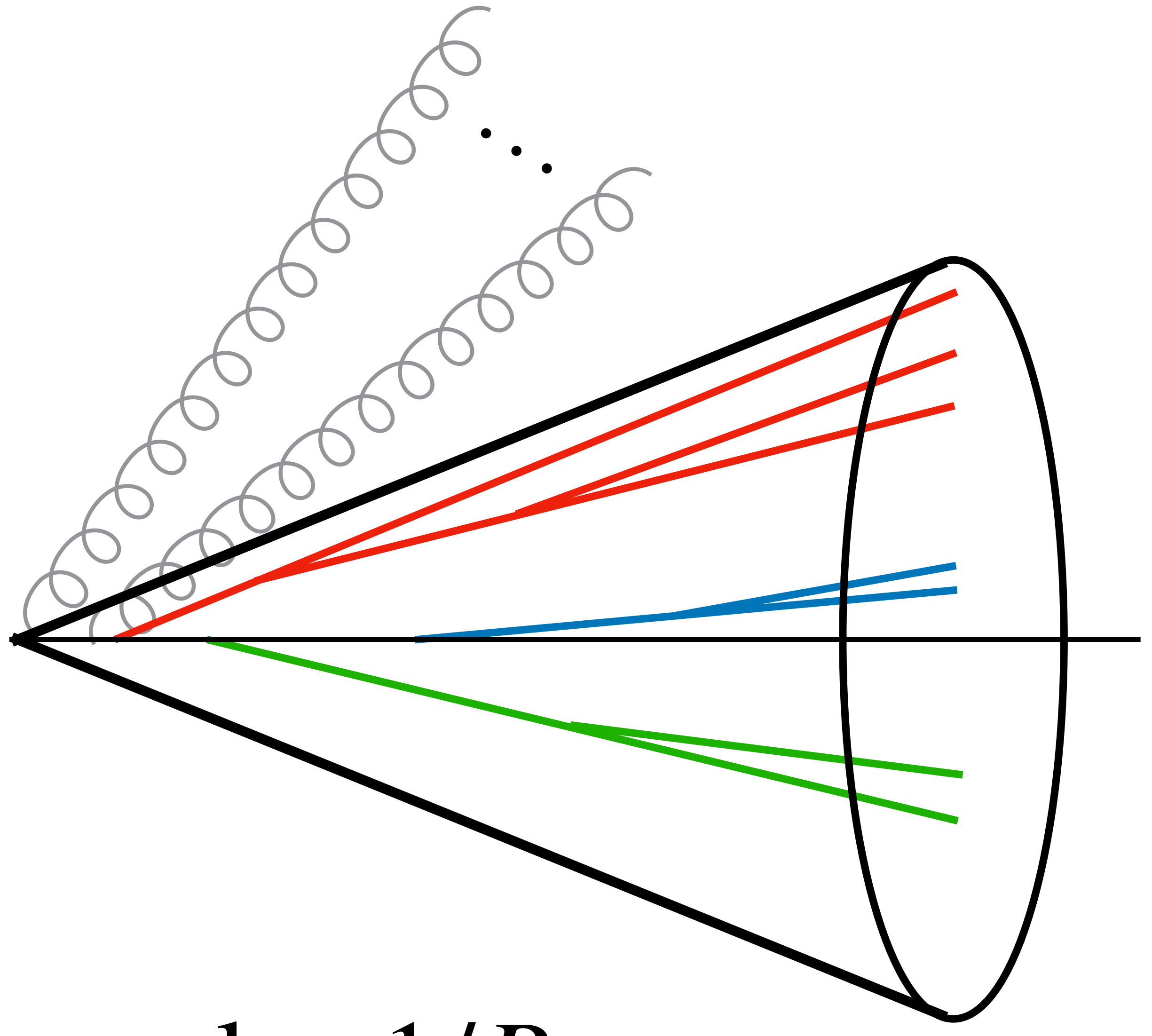
Non-perturbative effects (underlying event): $(\delta p_{\mathrm{T}})_{\mathrm{UE}} \simeq \frac{1}{2} \Lambda_{\mathrm{UE}} R^2$

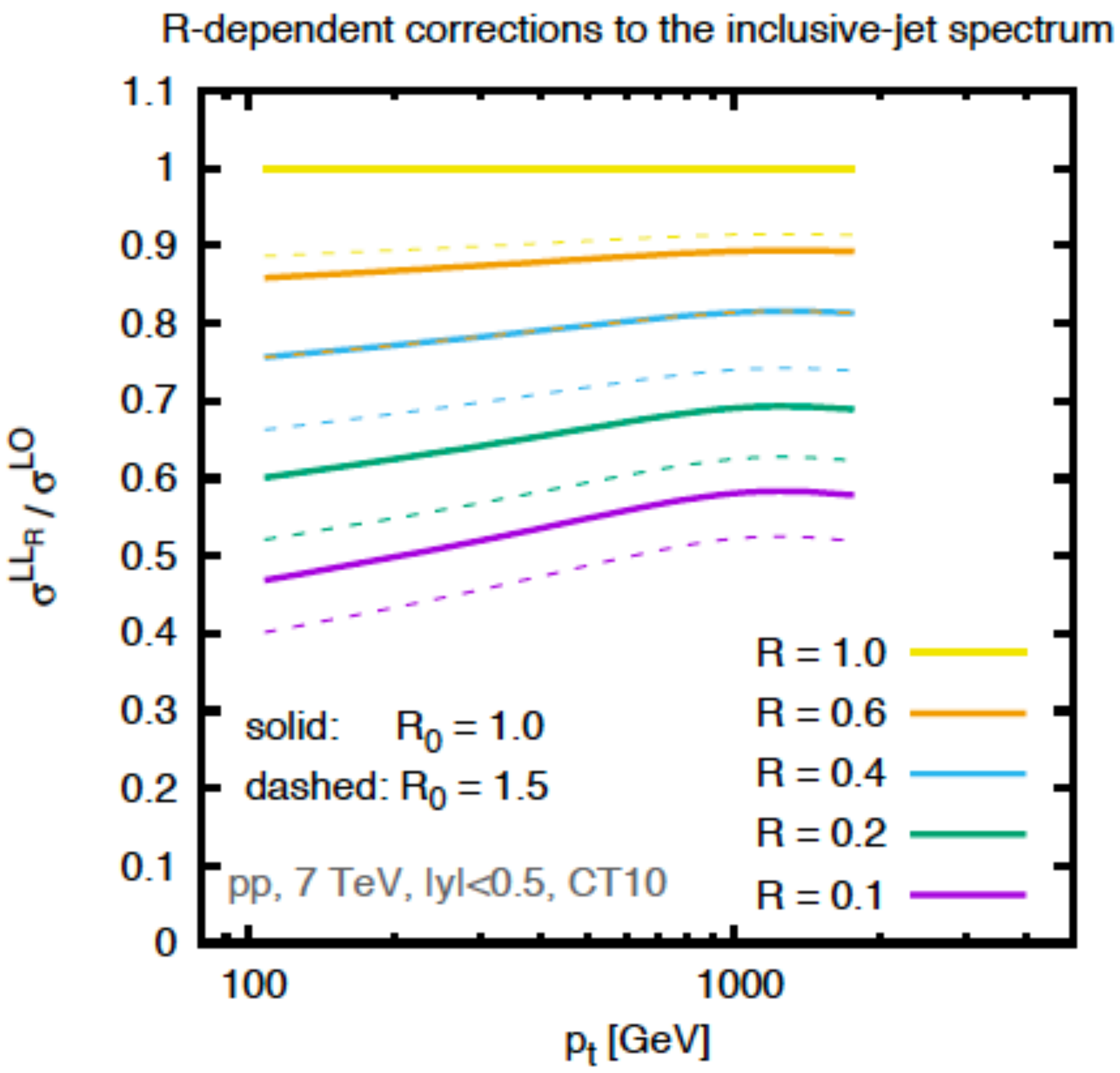
LOGARITHMIC RESUMMATION

Konishi, Ukawa, Veneziano Nucl. Phys. B1567 (1979);
Bassetto, Ciafaloni, Marchesini Phys. Rept. 100 (1983);
Dokshitzer, Khoze, Mueller, Troyan "Basics of Perturbative QCD" (1991)

Resummation of leading logarithmic contributions.

Jets inside jets: microjet spectrum.





Example: small-R resummation in $t = \log 1/R$:

$$\frac{\partial}{\partial t} f_{\mathrm{jet}/i}(z,t) = \int_0^1 \frac{\mathrm{d}z'}{z'} \frac{\alpha_s}{\pi} P_{ji}(z) f_{jet/j}\left(\frac{z}{z'}, t\right)$$

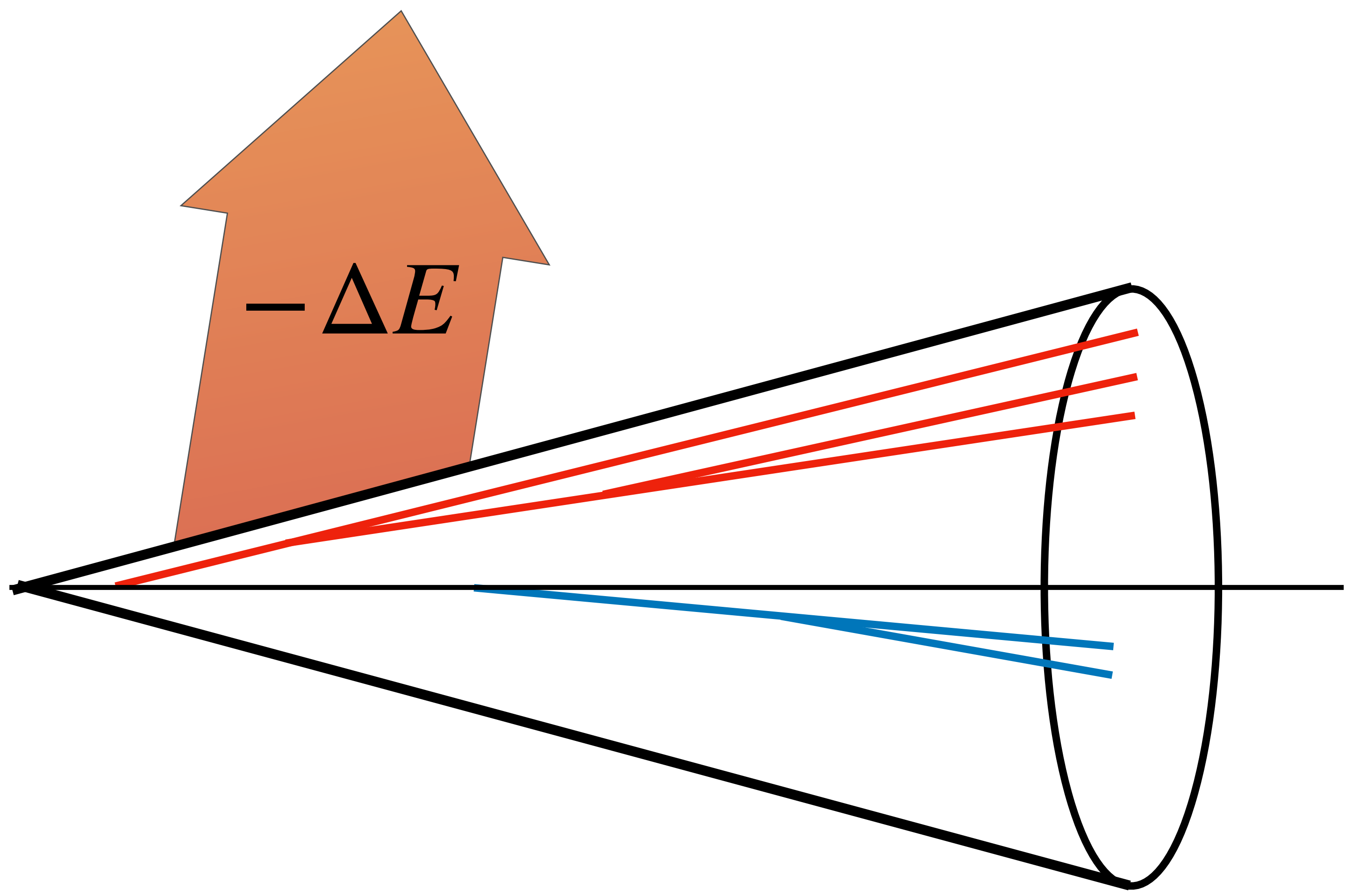
Evolution from hard scale to jet scale via DGLAP.

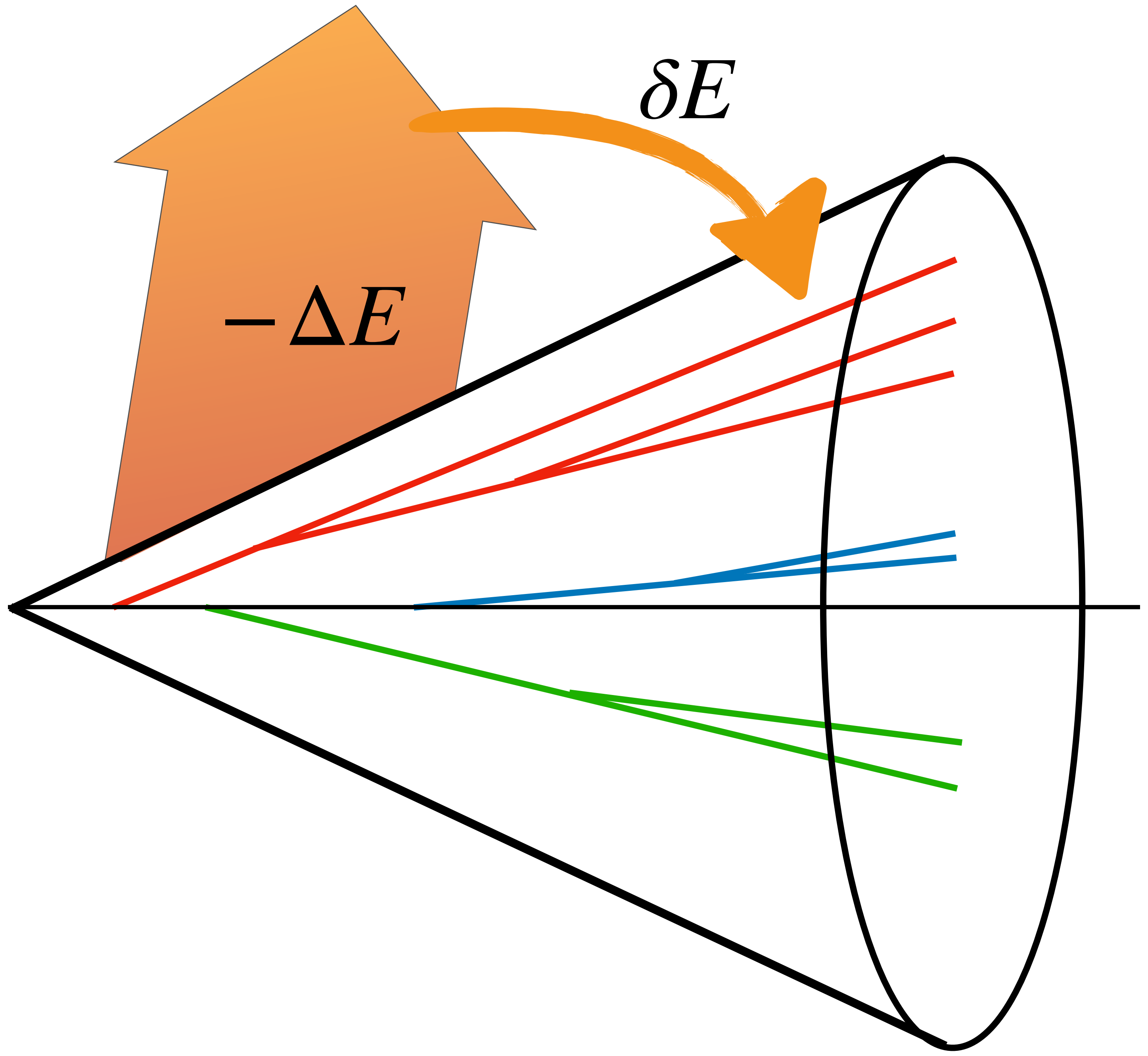
Dasgupta, Dreyer, Salam, Soyez 1411.5182, 1602.01110
Kang, Ringer, Vitev 1606.06732
Dai, Kim, Leibovitch 1606.07411

In the medium

- enhancement of energy loss out of the cone due to elastic and radiative processes
  - how much & how does energy flow out of the cone?
- jets are multi-parton objects with spacetime structure
  - how many partons are contributing to energy loss?
  - important to gain understanding from analytical approaches
- distribution of subjets within a jet
  - what is the distribution of fragments inside the cone?

GENERAL PICTURE





fewer color sources - less energy lost
easier for energy to flow out-of-cone

more color sources - more energy lost
recovery of lost energy

beware of biases: jet population is different!

Brewer, Tue (plenary)

QUENCHING OF PARTONIC HARD SPECTRUM

Baier, Dokshitzer, Mueller, Schiff (2001); Salgado, Wiedemann (2003)

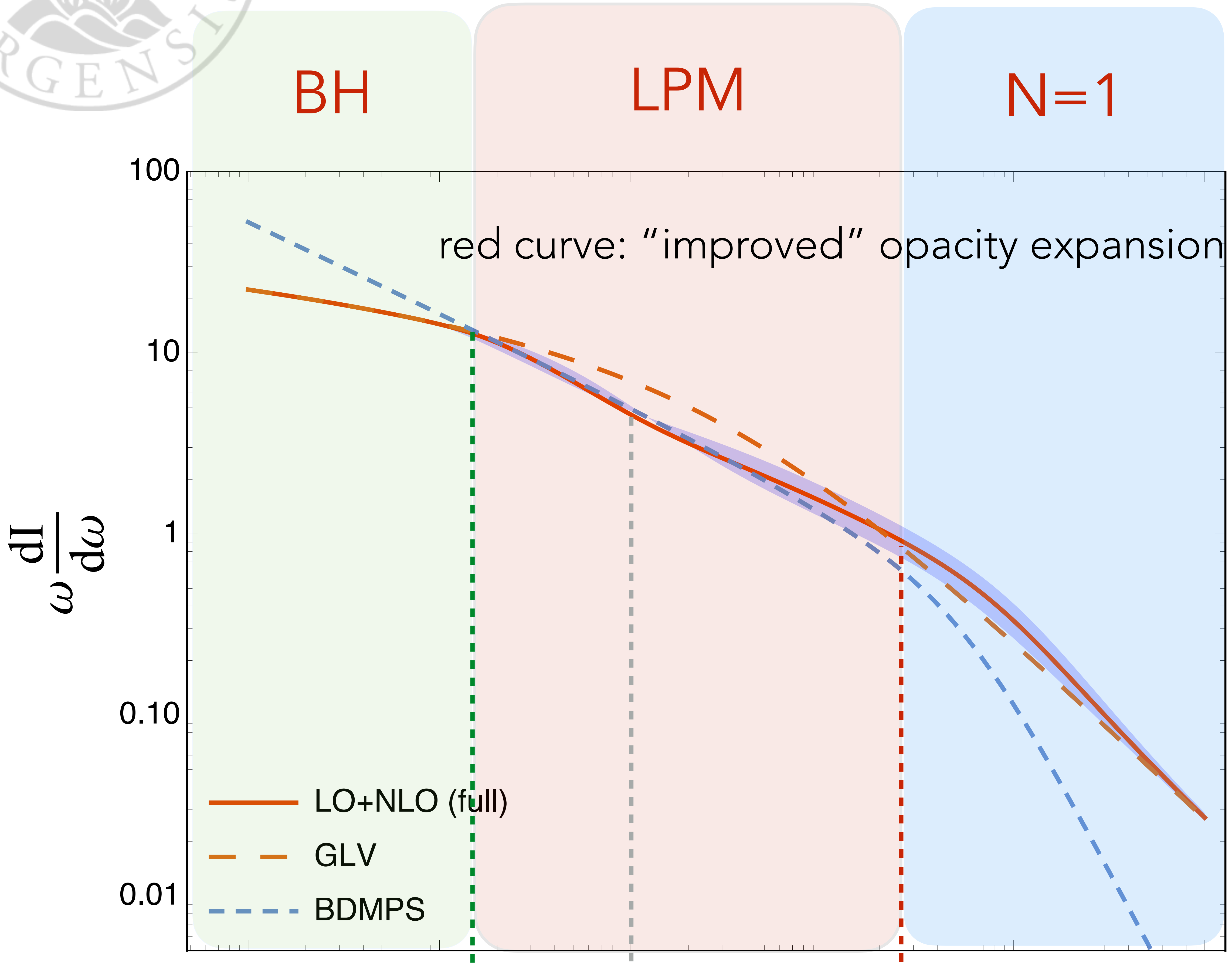
Quenching factor

$$\frac{\mathrm{d}\sigma_{\mathrm{med}}}{\mathrm{d}p_T} = \int_0^\infty \mathrm{d}\epsilon\, \mathcal{P}(\epsilon)\, \frac{\mathrm{d}\sigma_{\mathrm{vac}}}{\mathrm{d}p'_T}\bigg|_{p'_T = p_T + \epsilon} \approx \frac{\mathrm{d}\sigma_{\mathrm{vac}}}{\mathrm{d}p_T} \underbrace{\int_0^\infty \mathrm{d}\epsilon\, \mathcal{P}(\epsilon) \mathrm{e}^{-\epsilon \frac{n}{p_T}}}_{Q(p_T)}$$

- applies for small energy losses & steeply falling spectra - good approximation at RHIC/LHC
- energy loss distribution $P(\epsilon)$ includes fluctuations
- applies to a wide range of processes

RADIATIVE ENERGY LOSS

Mehtar-Tani, Tywoniuk 1910.02032
Mehtar-Tani, Barata 2004.02323



$$\hat{q}\lambda^2 \ll \alpha_s^2 \hat{q} L^2 \ll \hat{q} L^2$$

Momentum broadening $\langle \boldsymbol{k}^2 \rangle \sim \hat{q}t$ leads to modified bremsstrahlung spectrum → no collinear divergence!

$$\omega \frac{\mathrm{d}I}{\mathrm{d}\omega} = \frac{\alpha_s C_R}{\pi} \frac{L}{t_\mathrm{f}} = \frac{\alpha_s C_R}{\pi} \sqrt{\frac{\hat{q} L^2}{\omega}}$$

Bethe-Heitler regime ($t_\mathrm{f} \lesssim \lambda$)

LPM regime ($\lambda < t_\mathrm{f} < L$)

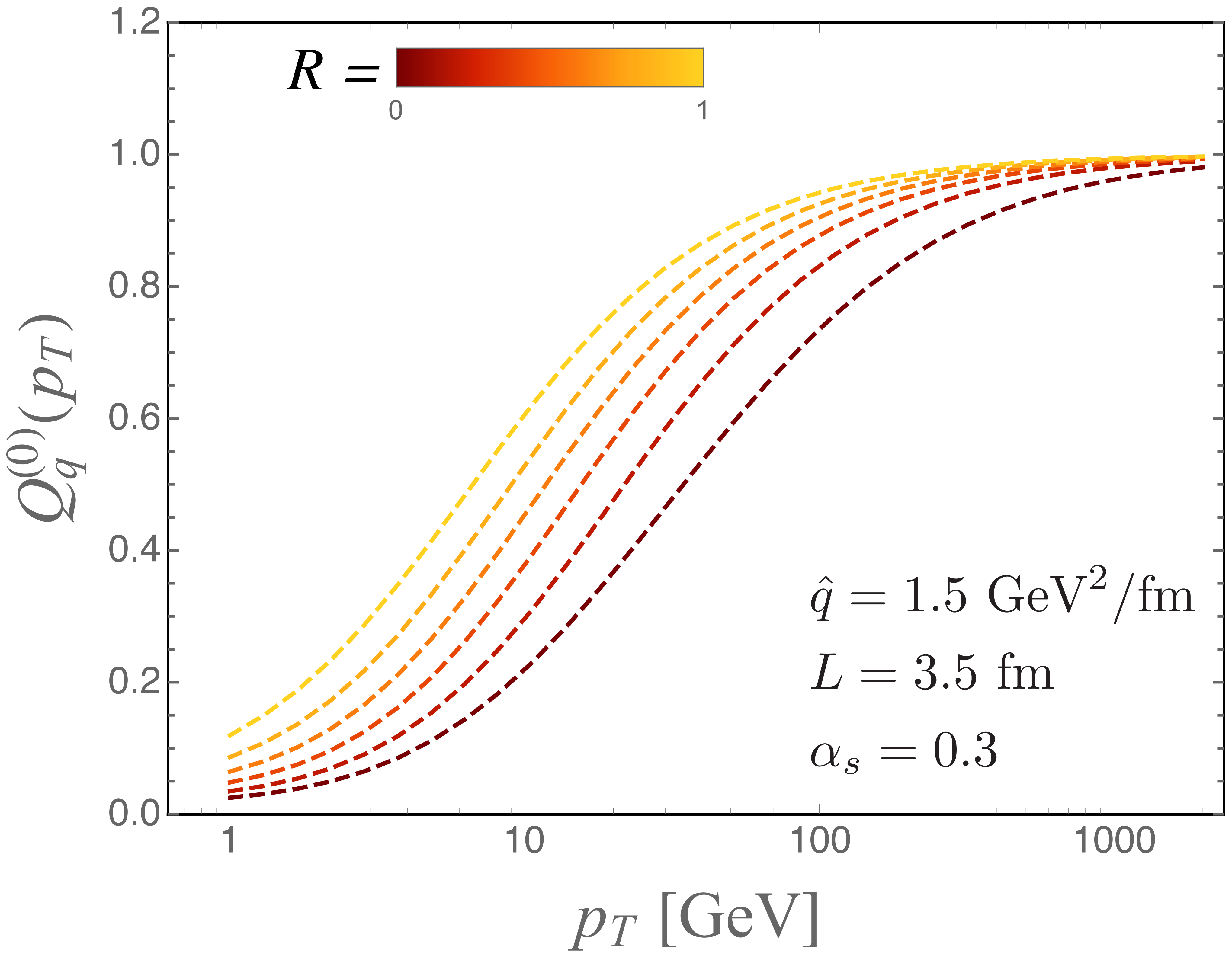
N=1 regime ($L < t_\mathrm{f} \sim E/\mu^2$)

Soft scale: copious, large angle gluons leading to energy loss & thermalization.

Blaizot, Dominguez, Iancu, Mehtar-Tani 1301.6102

BARE QUENCHING FACTOR

$$Q^{(0)}(p_T) = \exp\left[-\int_0^\infty \mathrm{d}\omega \, \frac{\mathrm{d}I_>}{\mathrm{d}\omega}\left(1 - \mathrm{e}^{-\omega \frac{n}{p_T}}\right)\right]$$



radiative & elastic energy loss out of the jet cone

recovery of energy at large angles:

- hard gluons stay within cone
- soft gluons thermalize and drift back into the cone

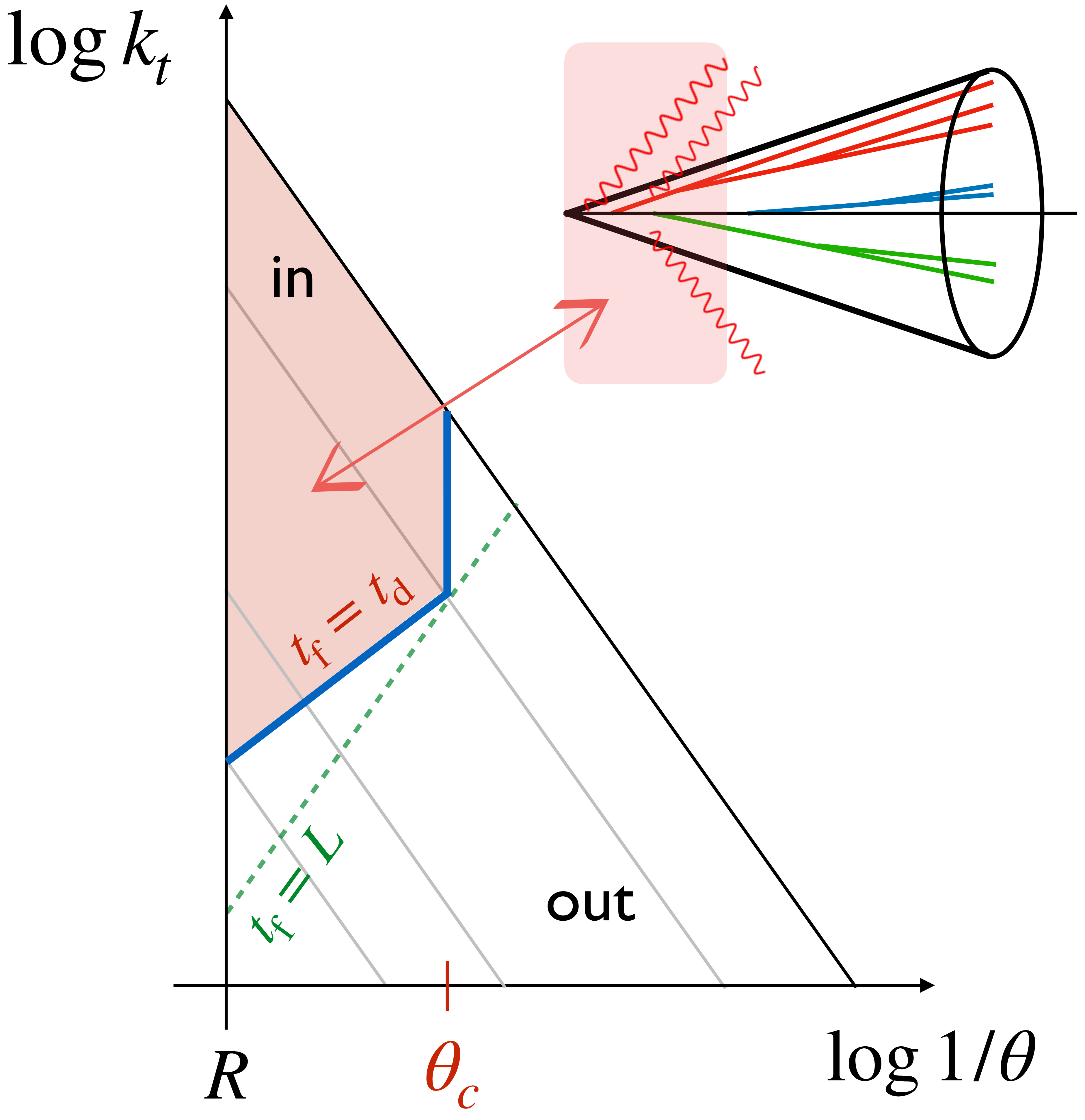
Casimir scaling: $Q_q(p_T) \approx \left(Q_g(p_T)\right)^{C_F/C_A}$

Factorization: $Q_{\rm tot}(p_T) = Q_{\rm rad}(p_T) \times Q_{\rm el}(p_T) \times \cdots$

[We only consider rad in this talk.]

Phase space analysis

Y. Mehtar-Tani, KT 1706.06047, 1707.07361
Caucal, Iancu, Mueller, Soyez 1801.09703



Vacuum emissions w/ $k_t^2 > \sqrt{\hat{q}\omega}$ and $\theta > \theta_c$ are emitted inside plasma and will eventually be resolved by the medium (red area).

At border: all inside emissions get quenched

How many modes are emitted inside?

$$(\mathrm{PS})_{\mathrm{in}} \approx 2\frac{\alpha_s C_R}{\pi} \log\frac{R}{\theta_c}\left(\log\frac{p_T}{\omega_c} + \frac{2}{3}\log\frac{R}{\theta_c}\right)$$

Potentially large and needs to be resummed.

Obs: phase space wo/coherence effects $t_f < L$ is larger $\propto \log^2 p_T$

Effective theory of jet quenching

Mehtar-Tani, KT in preparation

A probabilistic picture can be established due to the separation of jet and medium scales.

Outside of the medium, we have AO vacuum (vetoed shower):

$$Z_{\rm out}(p,R) = u(p) + \int^R {\rm d}\Pi\, (1-\Theta_{\rm in}) \left[Z_{\rm out}(zp,\theta) Z_{\rm out}((1-z)p,\theta) - Z_{\rm out}(p,\theta)\right]$$

The functions *u(p)* are "probing functions" of *measured particles*.

Vacuum-like (vetoed) AO shower inside the medium

$$Z(p,R) = Q(p_{\rm T}) Z_{\rm out}(p,1) + \int^R {\rm d}\Pi\, \Theta_{\rm in} \left[Z(zp,\theta) Z((1-z)p,\theta) - Z(p,\theta)\right]$$

accounts for quenching through iterative use of GF

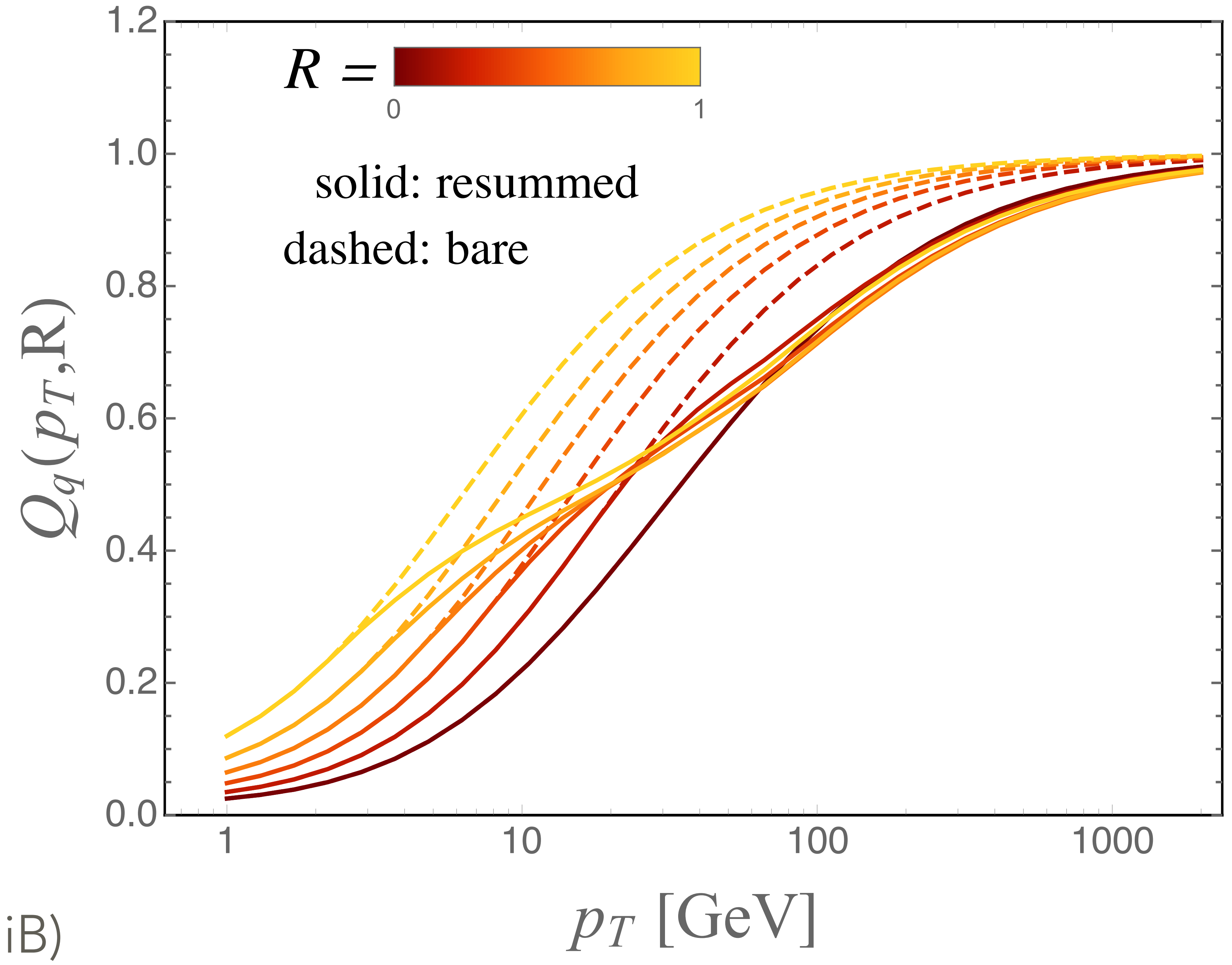
RESUMMED QUENCHING FACTOR

Mehtar-Tani, KT 1707.07361
Mehtar-Tani, Pablos, KT in preparation

Non-trivial normalization of the GF: $Z(p, R; \{u=1\}) = Q(p,R)$!

$$Q(p,R) = Q(p_{\rm T}) + \int^R d\Pi\, \Theta_{\rm in} \left[Q(zp,\theta) Q((1-z)p,\theta) - Q(p,\theta) \right]$$

coupled eqs for non-linear evolution of quenching



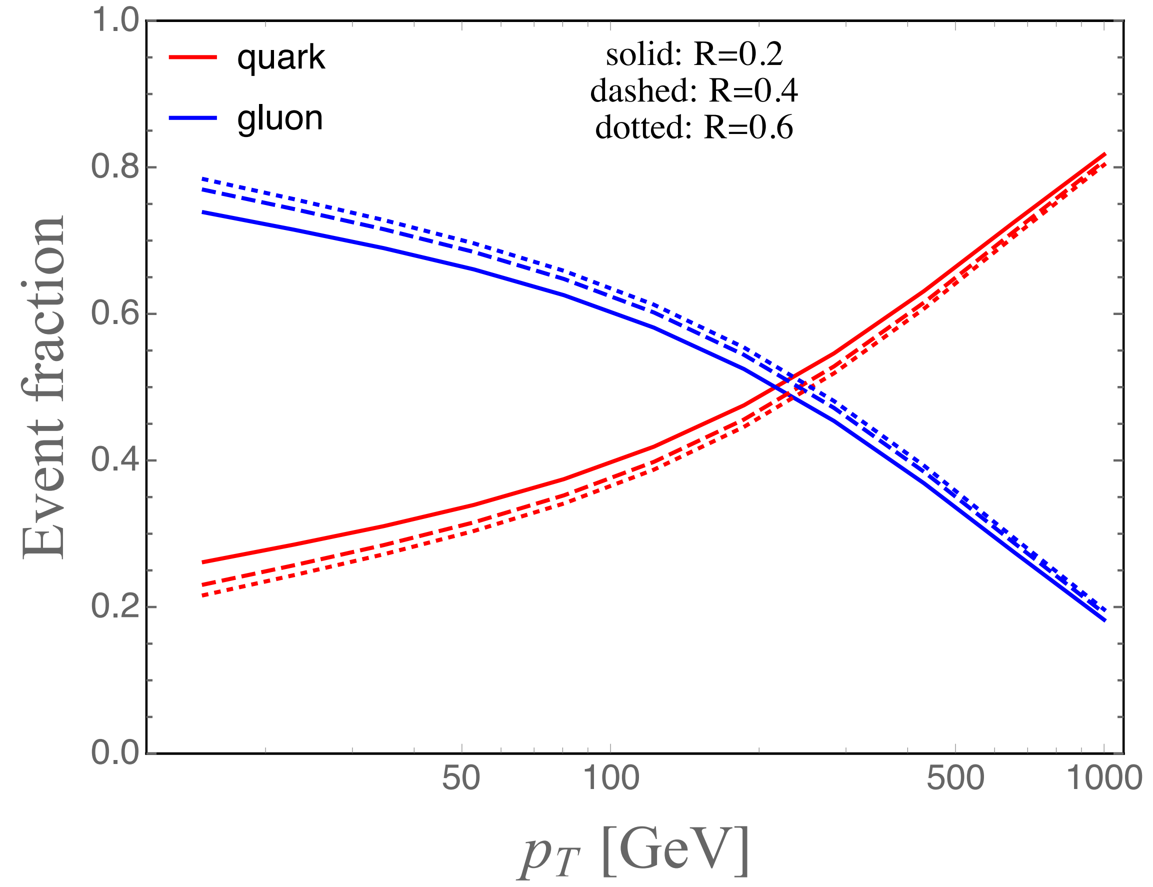
Approximately:

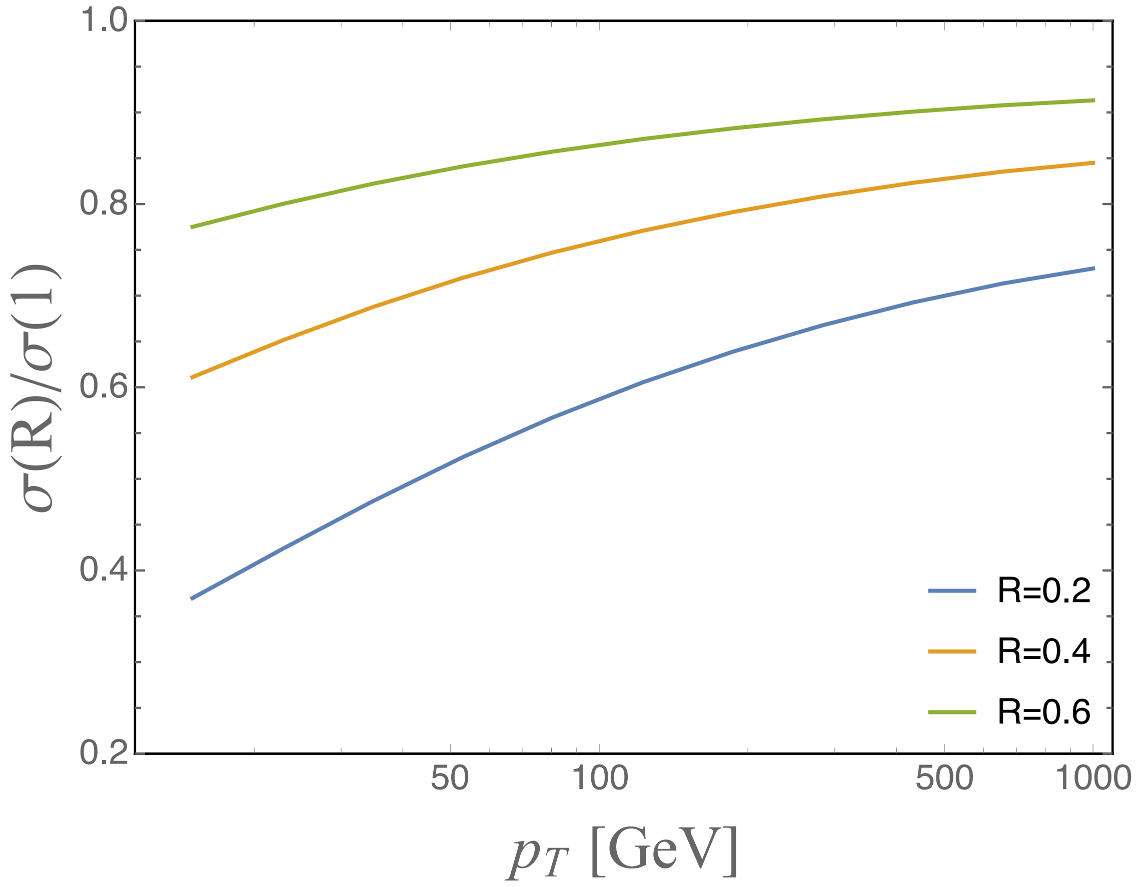
$$Q_i(p_T, R) = Q_i(p_T) \exp\left[\int^R d\Pi\, \Theta_{\rm in} \left(Q_g(p_T) - 1 \right) \right]$$

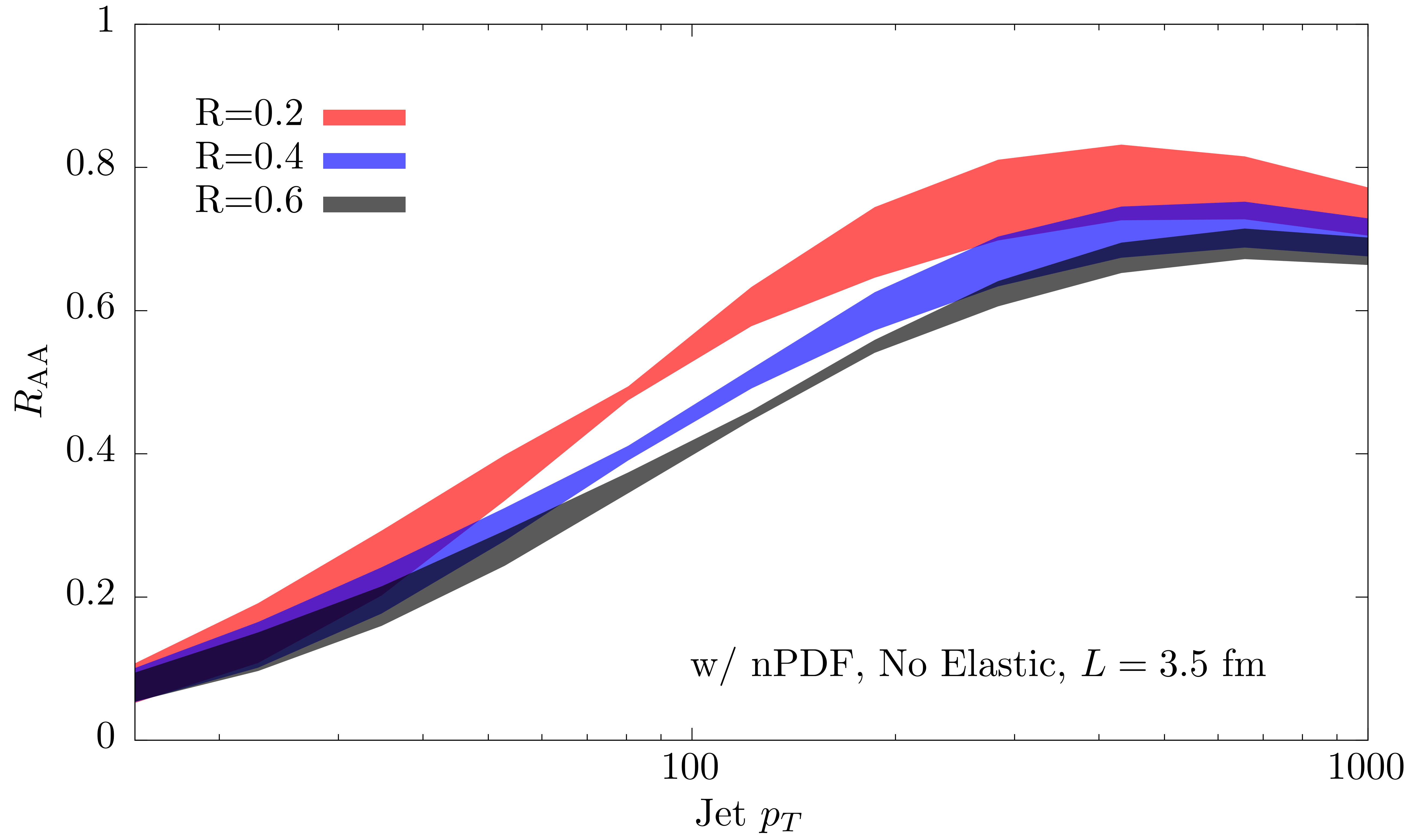
The R-dependence is much milder than for bare quenching!

Nuclear modification factor

Mehtar-Tani, Pablos, KT in preparation







bands correspond to varying θ_c by a factor~2 to gauge sub-leading log contributions.

Full calculation in collinear factorization, LO+LL (w/ EPS09 LO nPDFs)

- medium parameters tuned to reproduce R_{AA} at p_T=100 GeV and R=0.4.

OUTLOOK

- analytical calculation implementing the impact of jet fragmentation on quenching: indispensable for high-p_T jet observables
- recovery of energy at large angles is non-perturbative
  - strongly affected by choice of phase space for quenching
- $\hat{q}$ is a measure of both the amount of energy lost & the resolution properties of the medium (color coherence)
  - R_{AA} vs. R a rich observable to probe regimes

Backup

JET FRAGMENTATION FROM GF

R-dependence of the jet spectrum in terms of a jet fragmentation function

$$\frac{\mathrm{d}\sigma^{\mathrm{jet}}(R)}{\mathrm{d}p_T} = \sum_{i=q,g} \frac{\mathrm{d}\sigma_i}{\mathrm{d}p_{\mathrm{T}}} \underbrace{\int_0^1 \mathrm{d}z\, z^{n_i(p_T)-1} f_{\mathrm{jet}/i}(z,t)}_{f^{(n)}(z)}$$

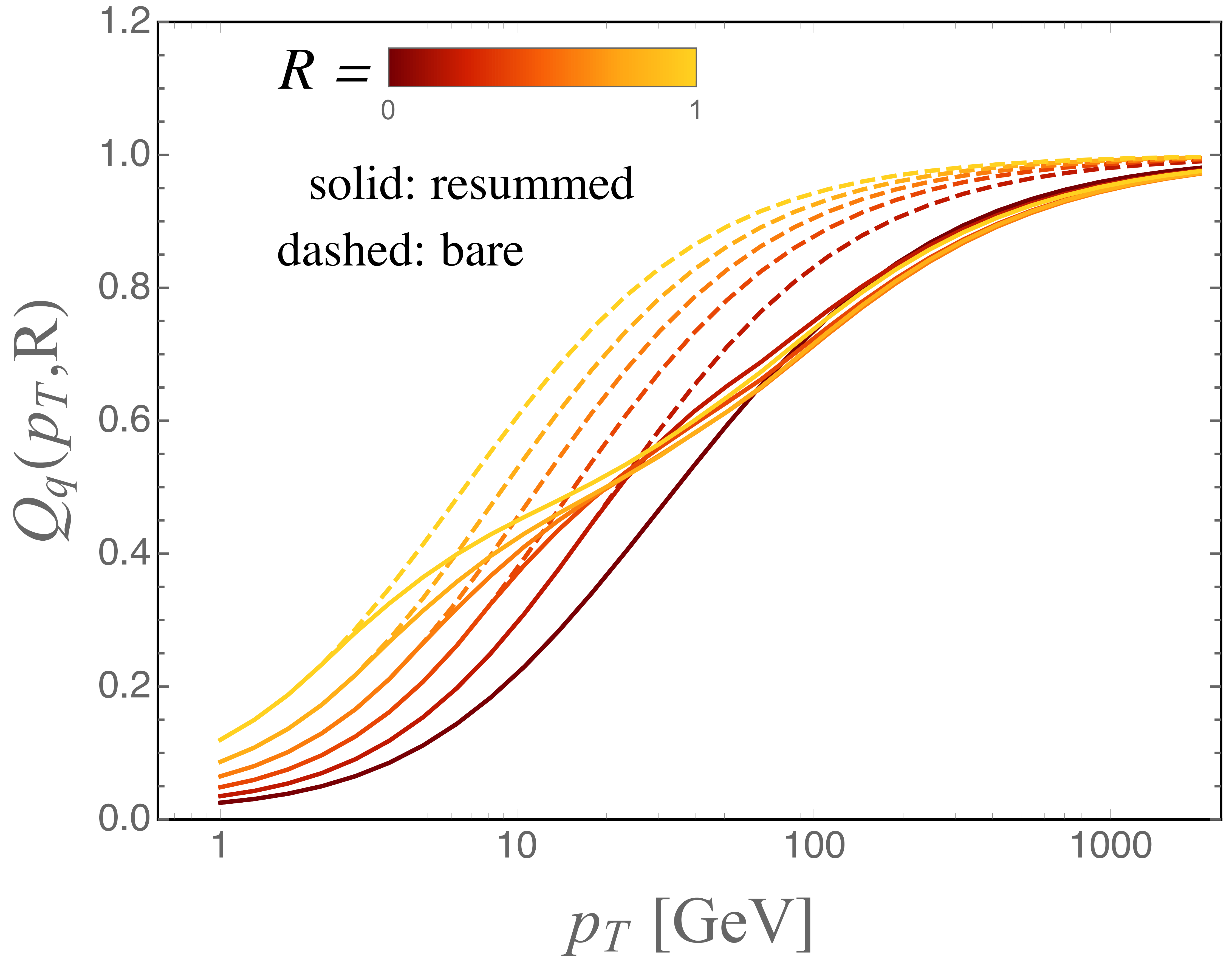
Quenched DGLAP equations:

$$\frac{\partial}{\partial \log\theta} \begin{pmatrix} f_q^{(n)}(p,\theta) \\ f_g^{(n)}(p,\theta) \end{pmatrix} = \begin{pmatrix} \gamma_{qq}^{\mathrm{med}} & \gamma_{qg}^{\mathrm{med}} \\ \gamma_{gq}^{\mathrm{med}} & \gamma_{gg}^{\mathrm{med}} \end{pmatrix} \begin{pmatrix} f_q^{(n)}(p,\theta) \\ f_g^{(n)}(p,\theta) \end{pmatrix}$$

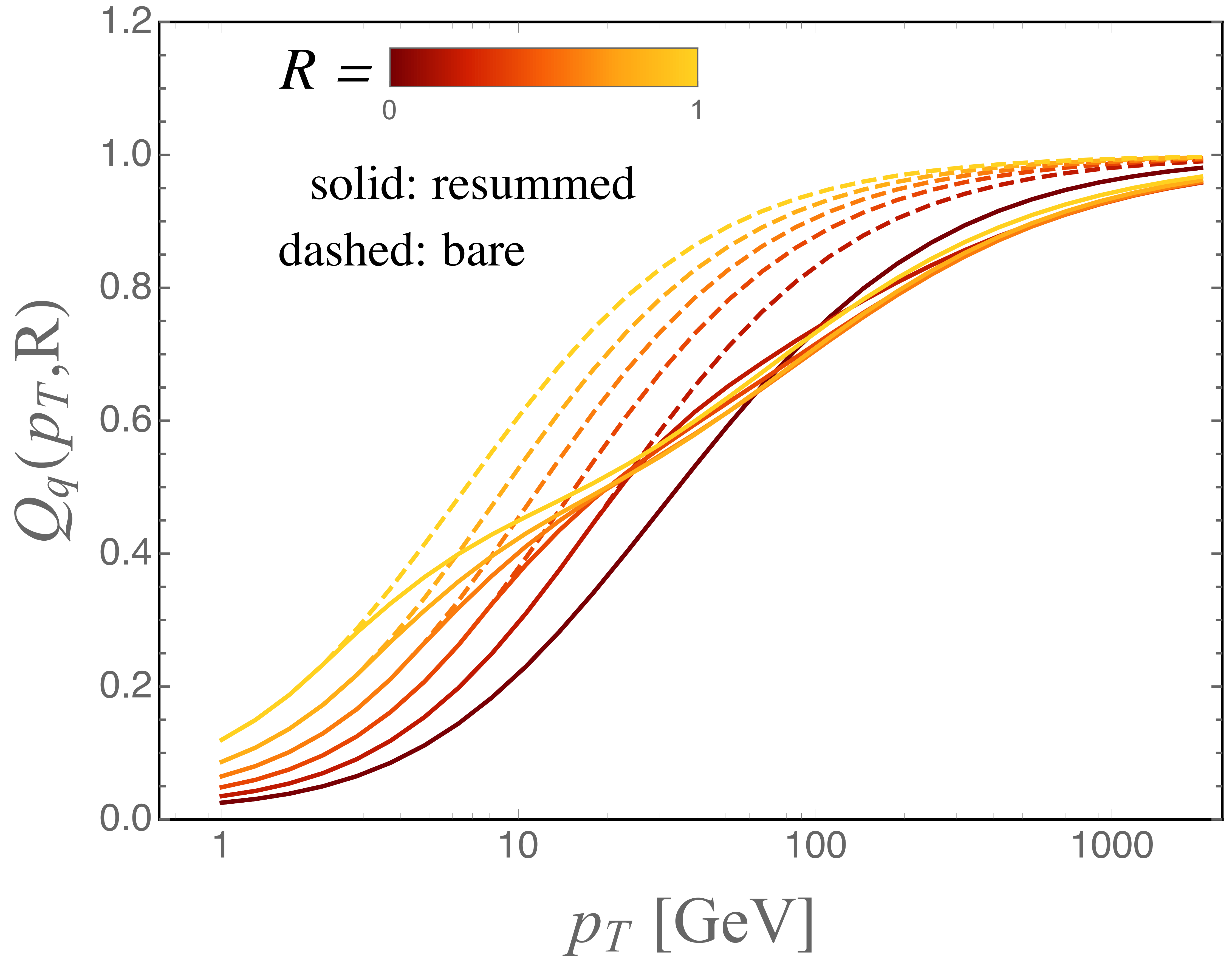
- with boundary condition $f_i^{(n)}(p,R) = Q_i(p,R)$

ROLE OF THE PHASE SPACE

coherent phase space



decoherent phase space



unfair comparison: should retune medium parameters!