# EFT-based factorization for jet quenching observables

Yacine Mehtar-Tani (BNL) 2409.05957 [hep-ph]
In collaboration with F. Ringer, B. Singh, V. Vaidya

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# Motivation

- Build a factorization approach for jet quenching to all orders in perturbation theory
- Method: Scale separation in Effective Field Theory (EFT) framework

# Jet quenching timeline

Medium-induced radiation

1990-2000

Medium-induced cascade

2000-2015

Color coherence

2010

Leading log resummation

2017-present

MC event generator

2010-present

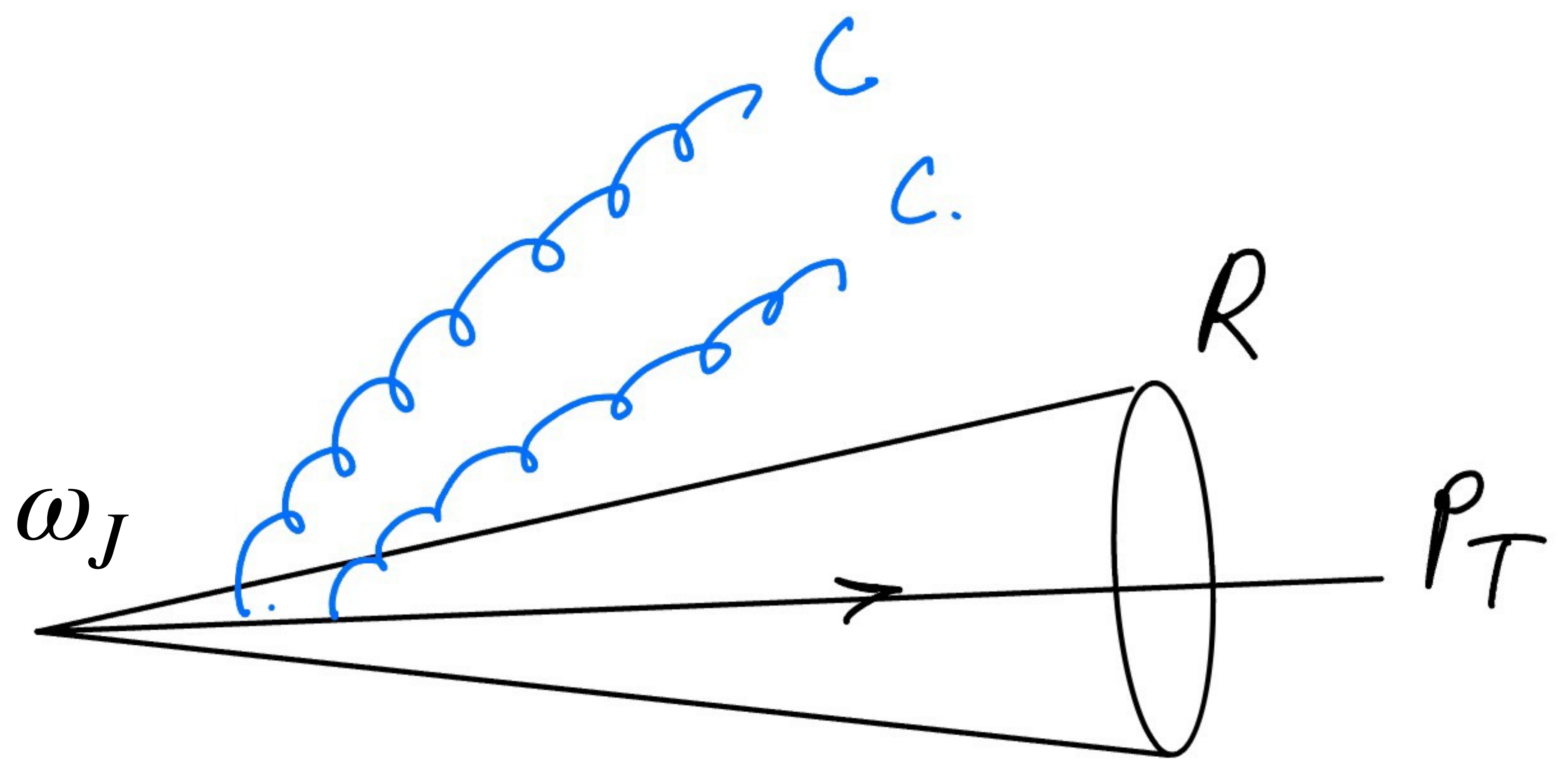
All orders factorization?

# Collinear jet function:
# from pp to HIC collisions

# Jet production in proton-proton

- Factorization of the **hard matrix** element and collinear jet function

$$\frac{d\sigma}{dp_T} \sim \int_0^1 \frac{dz}{z} H(p_T = z\omega_J, \mu)\, J(z, \omega_J, \mu)$$




Hard modes $p_h \sim p_T\,(1,1,1)$

Collinear mode $p_c \sim p_T\,(R^2, 1, R)$

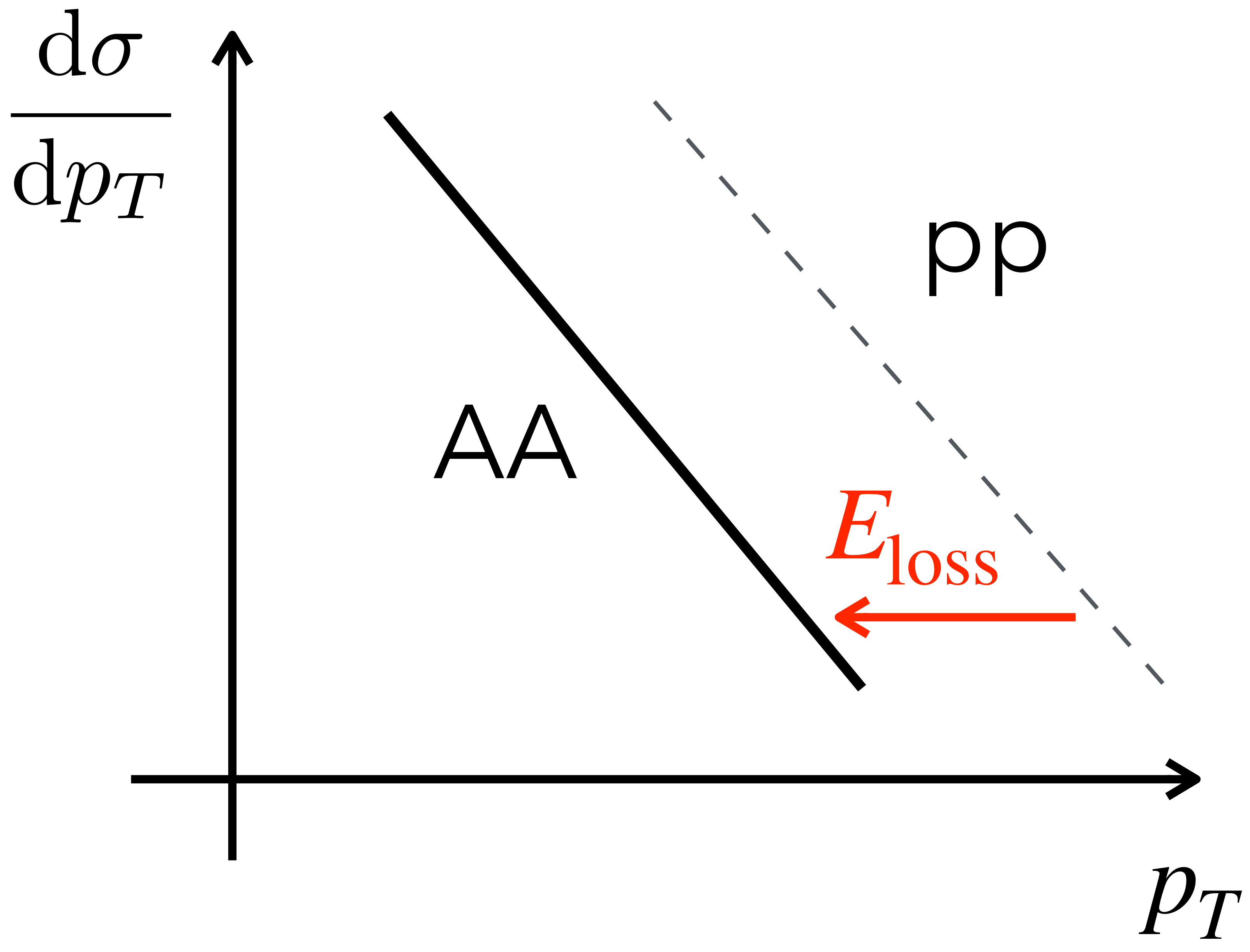
- Jet function obeys DGLAP which resums powers of $\alpha_s \ln R$ , where $R \ll 1$

[Dasgupta, Dreyer, Salam, Soyez (2015 ), Kang, Ringer, Vitev (2016)]

# Collinear-soft mode from energy loss

- Steep jet spectrum $n \gg 1 \implies$ Bias toward small energy loss

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T} \sim \frac{1}{(p_T + E_{\rm loss})^n} \simeq \frac{1}{p_T^n}\underbrace{\left(1 - \frac{nE_{\rm loss}}{p_T}\right)}_{R_{AA}} < 1$$

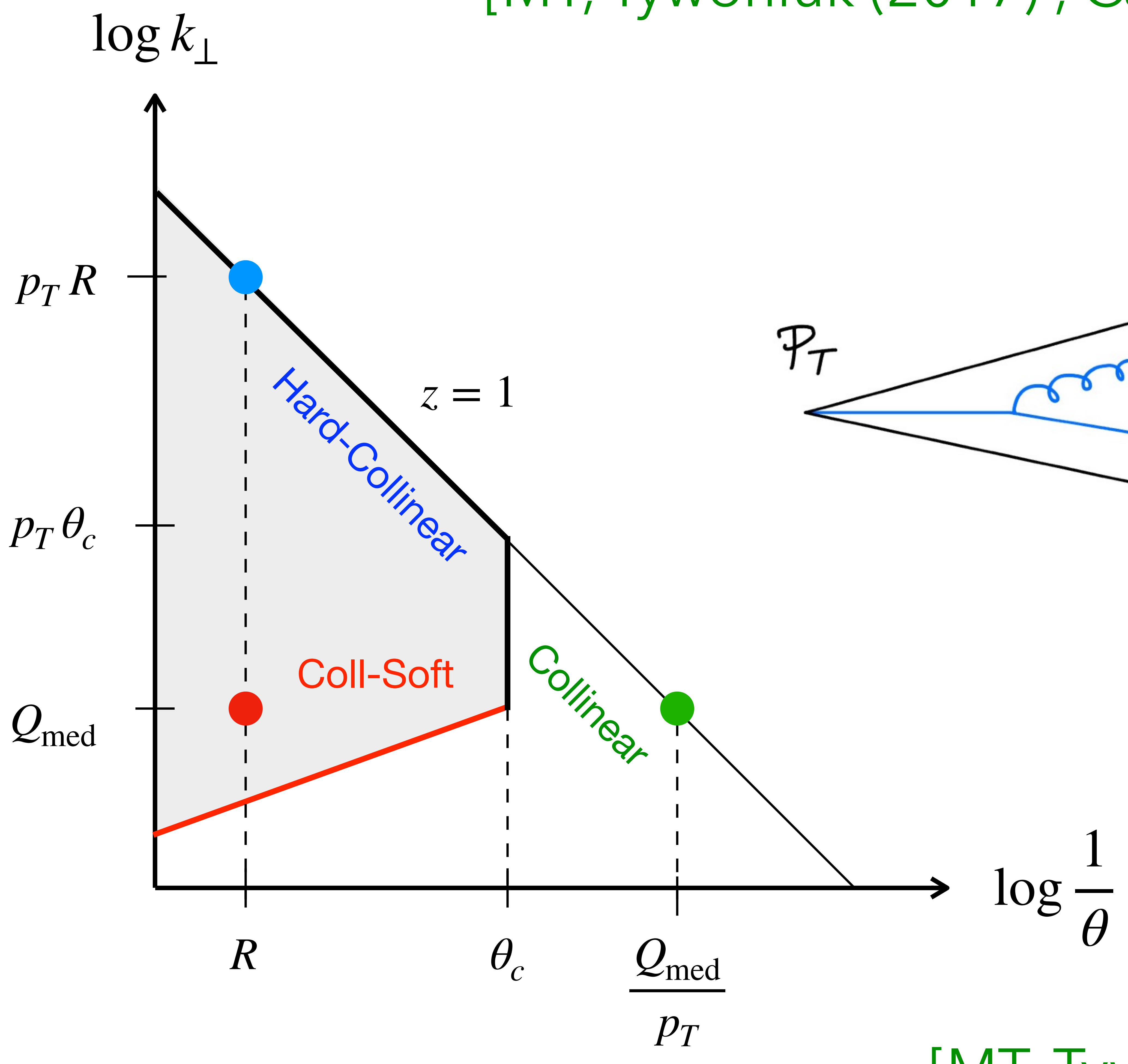


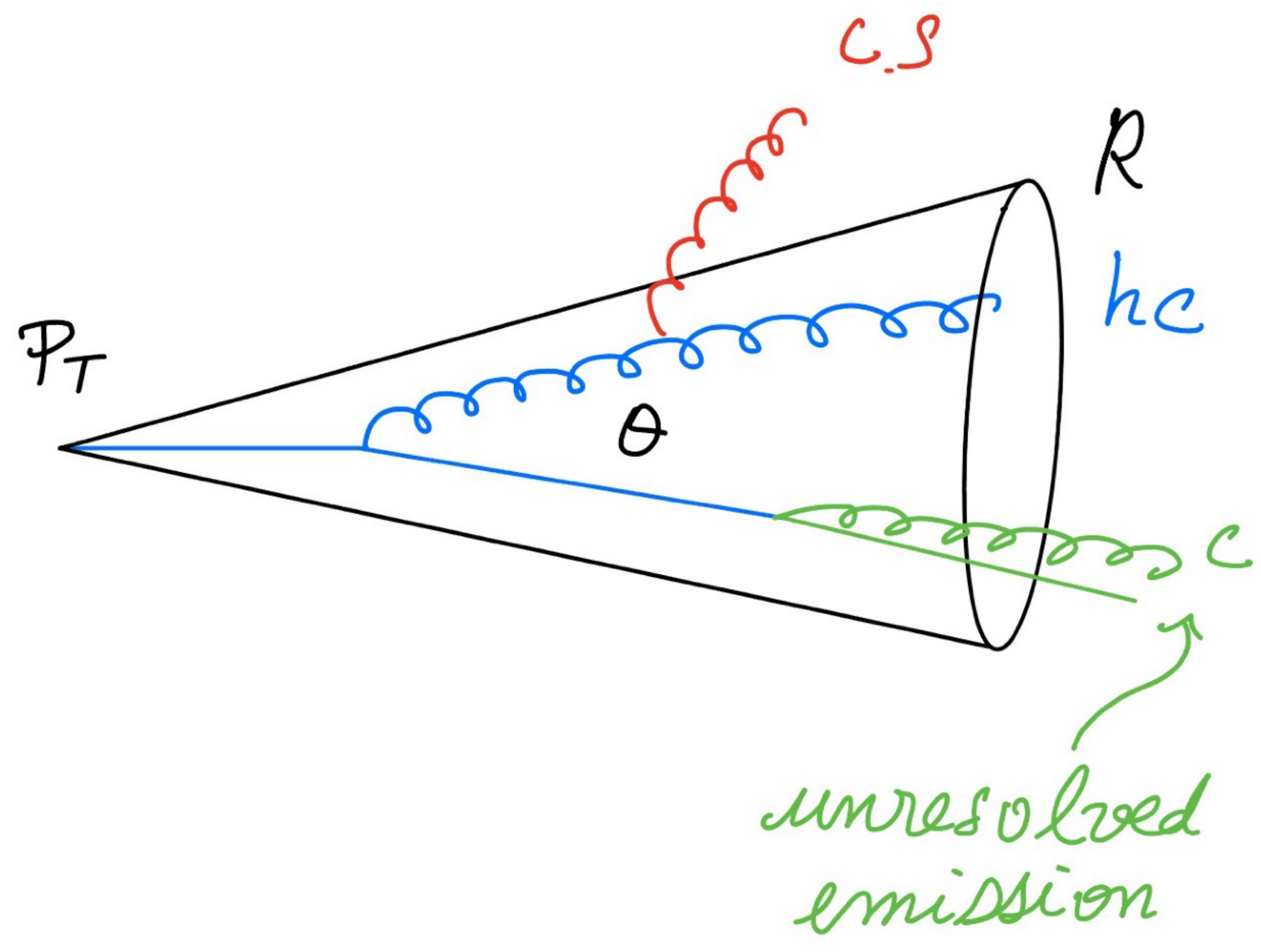

- Collinear-Soft mode $p_{cs} \sim p_T\, \beta\, (R^2, 1, R)$

$$\beta \sim \frac{E_{\rm loss}}{p_T} \sim \frac{1}{n} \ll 1$$

# Lund-Plane analysis

[MT, Tywoniuk (2017) , Caucal, Iancu, Mueller, Soyez (2018)]




- Transverse momentum broadening

$$Q_{\rm med} \sim \sqrt{\hat{q}L} \sim R^2 p_T$$

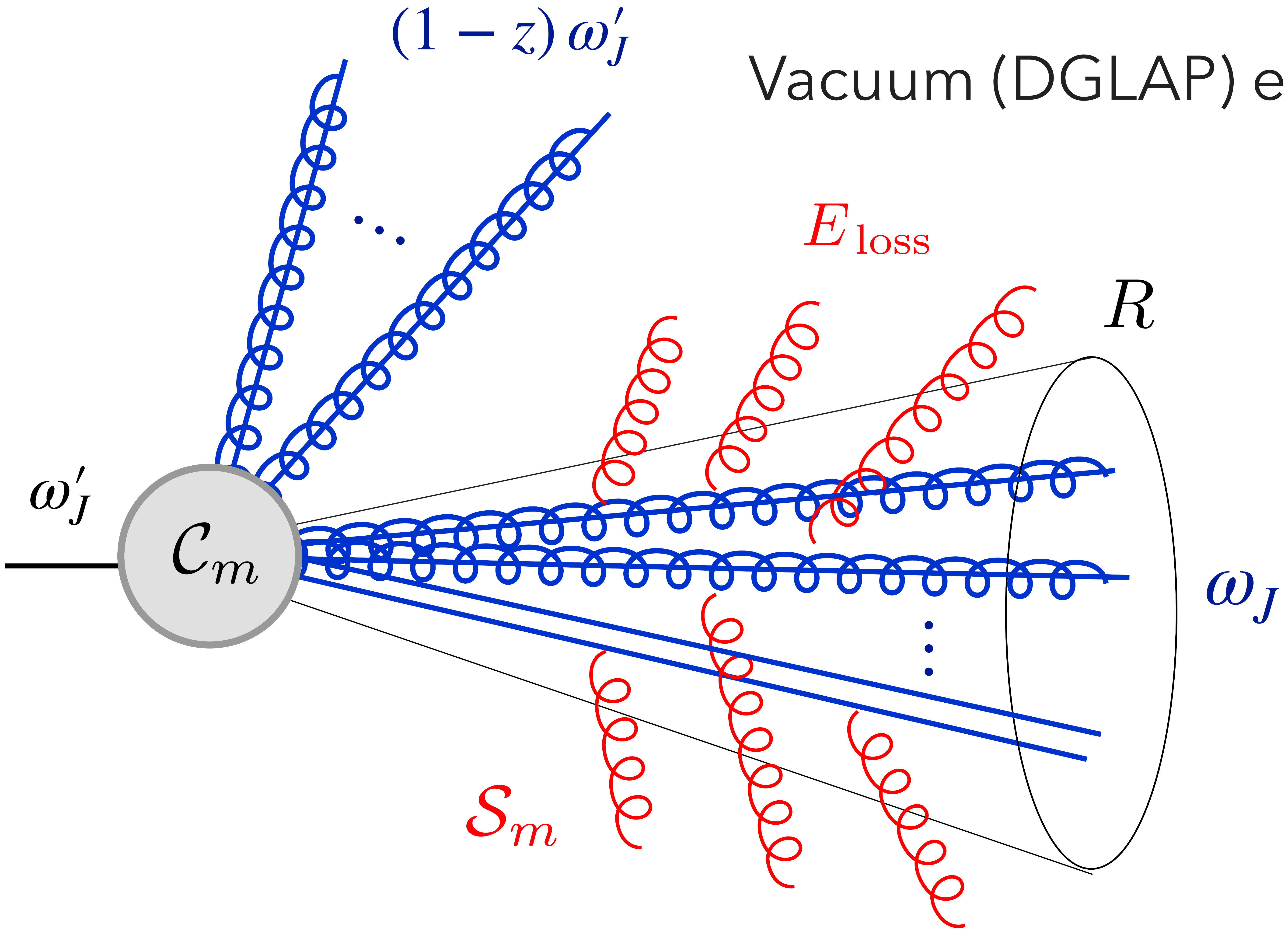
- Coherence angle: interference

$$\theta_c \sim \frac{1}{Q_{\rm med}} \sim \left(\sqrt{\hat{q}L^3}\right)^{-1/2}$$

[MT, Tywoniuk, Salgado, Casalderrey-Solana, Iancu (2011-2013)]

# Factorization in HIC collisions

# Collinear-soft mode from energy loss in HIC




Vacuum (DGLAP) evolution

Multiple subjet radiating
soft gluons

# Re-factorization of the jet function

$$J(z,\omega_J) = \int \mathrm{d}z' \int \mathrm{d}\epsilon \; \delta(\omega'_J - \omega_J - \epsilon) \sum_m C_m(\{n_i\}, z', \omega'_J \mu, \mu_{cs}) \otimes S(\{n_i\}, \epsilon, \mu_{cs})$$

- Collinear-soft function - energy loss distribution (similar form in vacuum)

$$S(\{n_i\},\epsilon) \equiv \sum_X \Theta_{alg}\, \delta(\epsilon - \sum \bar{n}\cdot p_{loss}) \langle \mathrm{med}| \bar{U}_0 U_1^\dagger ... U_m^\dagger |X\rangle\langle X| \bar{U}_m ... U_1 \bar{U}_0 |\mathrm{med}\rangle$$

- Wilson line along the m direction

$$U_m \equiv P \exp\left[ ig \int_0^1 \mathrm{d}s\, n\cdot A_{cs}(sn)\right]$$

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# Application: 1-subjet & 1-loop

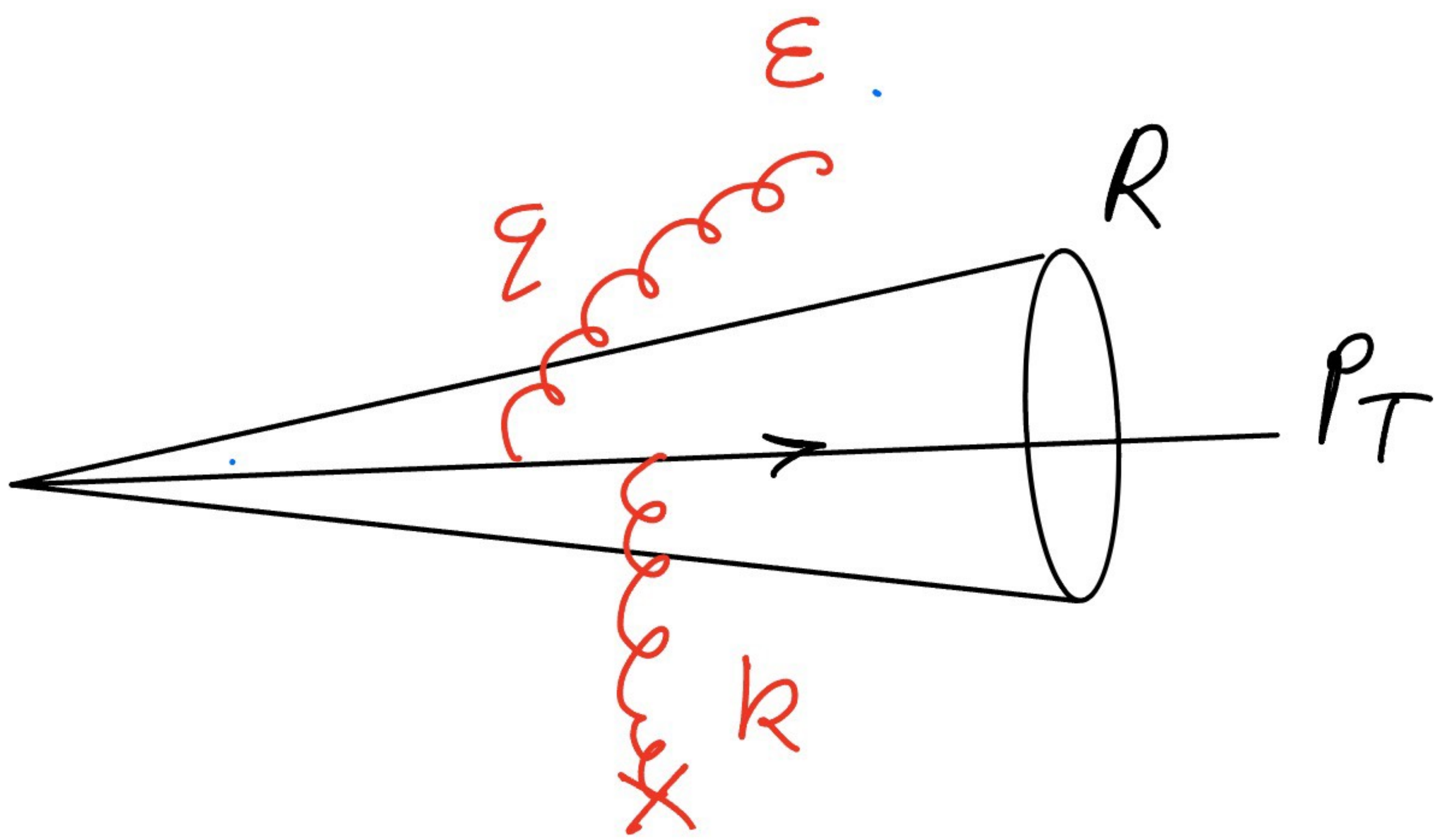
- Split soft-collinear fields (rapidity separation) → cs & Glauber

[Background field method (Balitsky (1988) Wiedemann 2000)] [Idilbi, Majumder (2008) Ovanesyan, Vitev, (2011) Stewart-Rothstein (2015)]

- At one loop & LO in opacity we obtain the cs anomalous dim and GLV (2001)

$$S_1(\varepsilon,\mu) = \delta(\epsilon) + \frac{4\alpha_s C_F}{(2\pi)^2}\mu^{-\epsilon}\int \frac{\mathrm{d}q^-}{q^-}\int \frac{\mathrm{d}^{2+\epsilon}\boldsymbol{q}}{\boldsymbol{q}^2}\left[\delta(q^- - \varepsilon) - \delta(\varepsilon)\right]\Theta(|\boldsymbol{q}| - Rq^-/2)$$

$$\times\left\{1 + \frac{2\boldsymbol{k}\cdot\boldsymbol{q}}{\boldsymbol{k}^2(\boldsymbol{q}-\boldsymbol{k})^2}\int \mathrm{d}x^-\left[1 - \cos\frac{(\boldsymbol{q}-\boldsymbol{k})^2}{2q^-}x^-\right]\varphi(\boldsymbol{k},x^-)\right\}$$




- The medium gluon distribution is related to the correlator

$$\langle A_G^+(\boldsymbol{k},x^-)A_G^+(\boldsymbol{k}',x'^-)\rangle \sim \delta(x^- - x'^-)\,\delta(\boldsymbol{k}-\boldsymbol{k}')\,\varphi(\boldsymbol{k},x^-)$$

# Summary and outlook

- In an EFT framework we have derived a factorization formula for jet observables in HIC
- In this approach: vacuum evolution and medium-induced processes are resummed in a collinear-soft function built of Wilson line correlators
- Application: multiple medium-induced radiation in a dense QGP (BDMPS), substructure observables, etc

Thank you!