Color Decoherence of Jets in HIC

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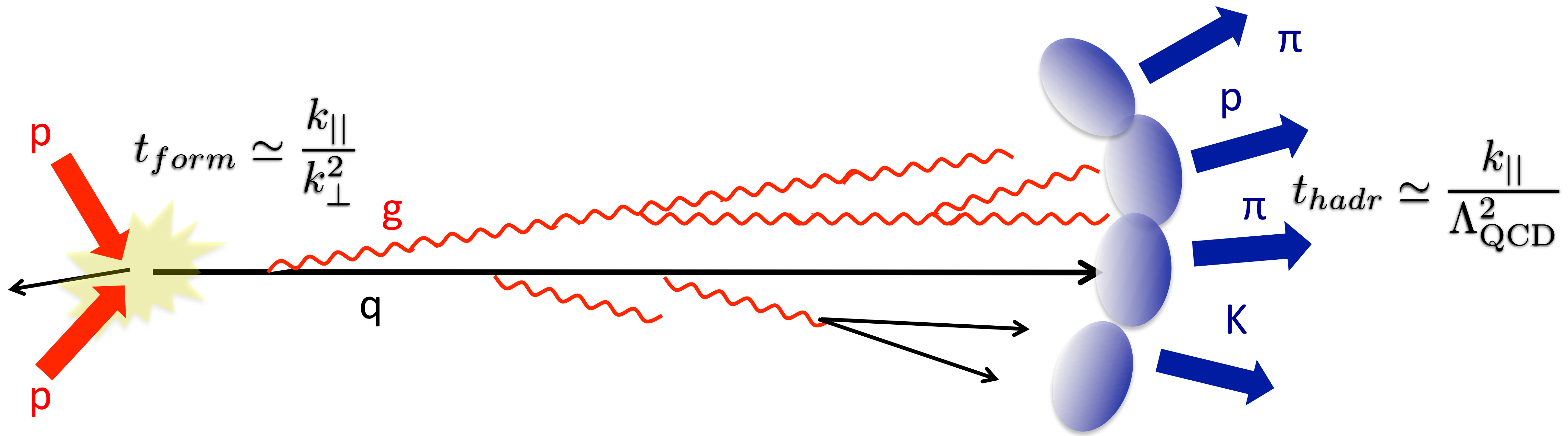
In collaboration with
C. A. Salgado and K. Tywoniuk

PRL 106 (2011) 122002, arXiv:1009.2965 [hep-ph]
PLB 707 (2011) 156, arXiv:1102.4317 [hep-ph]
JHEP 1204 (2012) 064, arXiv:1112.5031 [hep-ph]
arXiv:1105:1346 [hep-ph]
arXiv: 1205.5739 [hep-ph] (To appear in JHEP)

August 16, 2012
Quark Matter 2012
Washington DC

JETS IN VACUUM

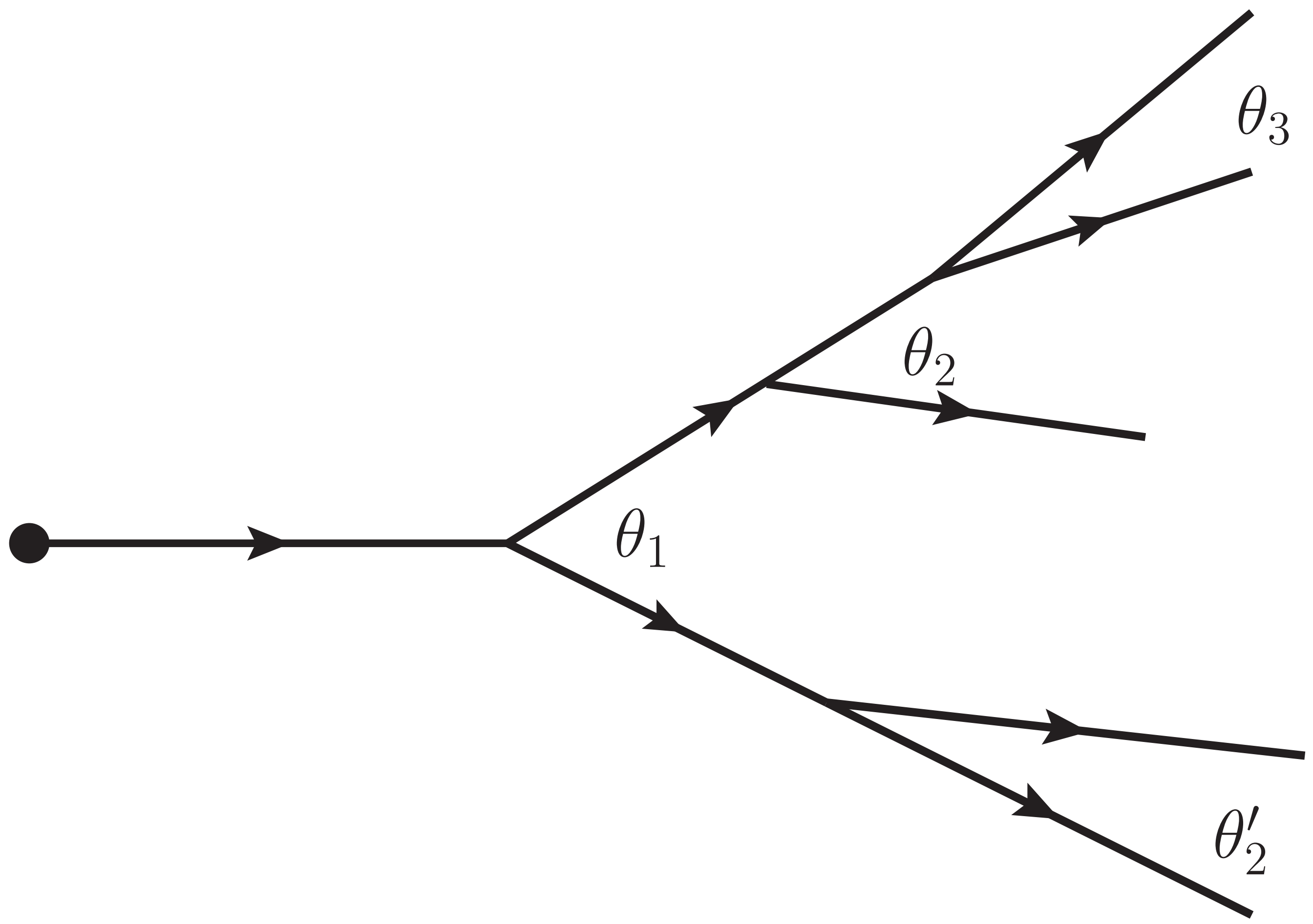


- Originally a hard parton (quark/gluon) which fragments into many partons with virtuality down to a non-perturbative scale where it hadronizes
- LPHD: Hadronization does not affect inclusive observables (jet shape, energy distribution etc..)

Large time domain for pQCD: $\frac{1}{\sqrt{s}} < t < \frac{\sqrt{s}}{\Lambda^2_{\rm QCD}}$

JETS IN VACUUM

[Bassetto, Mueller, Ciafaloni, Marchesini, Dokshitzer, Khoze, Troyan, Fadin, Lipatov, 80's]



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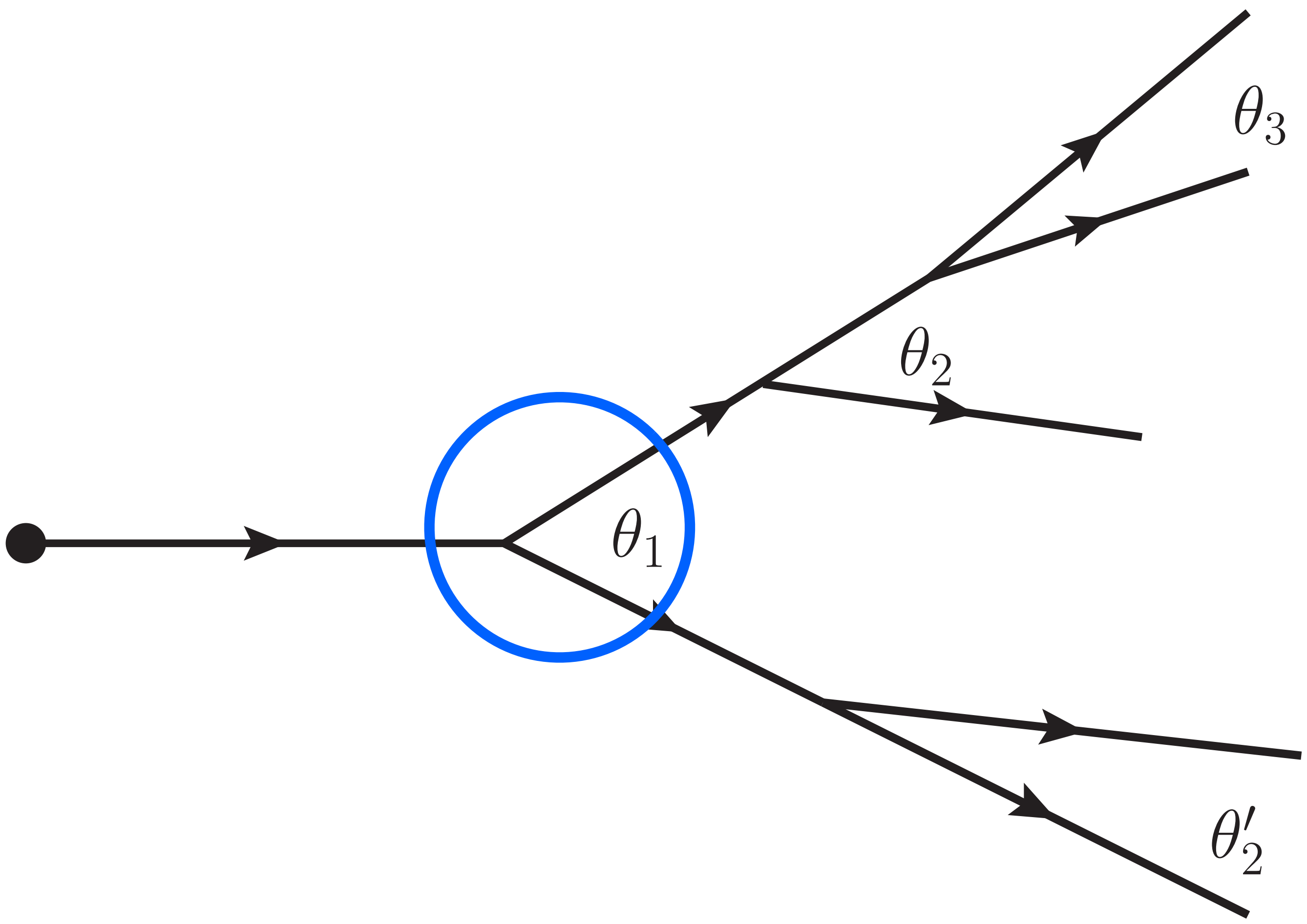

Leading Logarithms

$$dP \propto \frac{\alpha_s C_R}{\pi} \frac{d\omega}{\omega} \frac{d\theta}{\theta}$$

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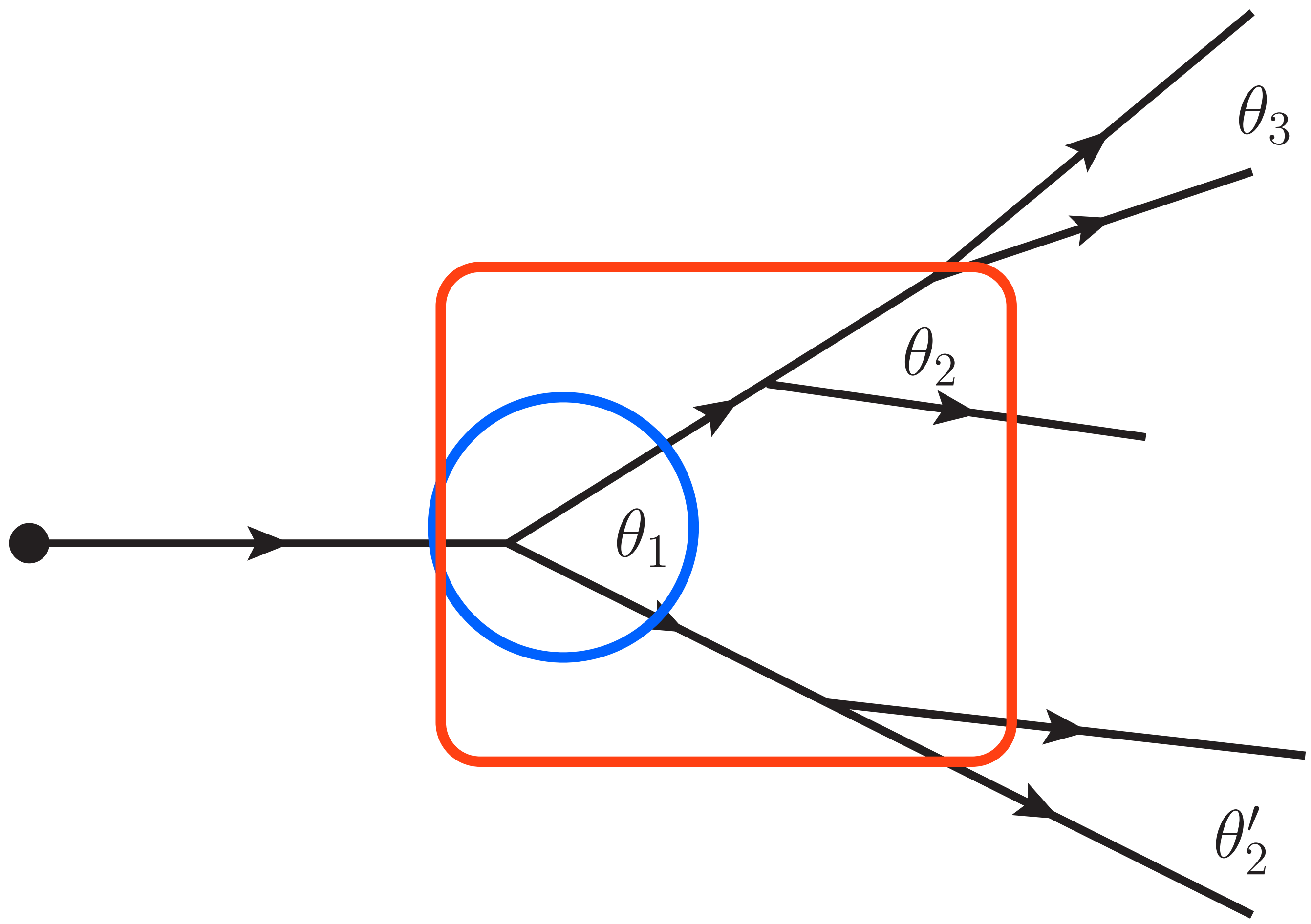

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Angular ordering

$$d^2P \propto \Theta(\theta_1 - \theta_2)\, dP_1\, dP_2$$

JETS IN VACUUM

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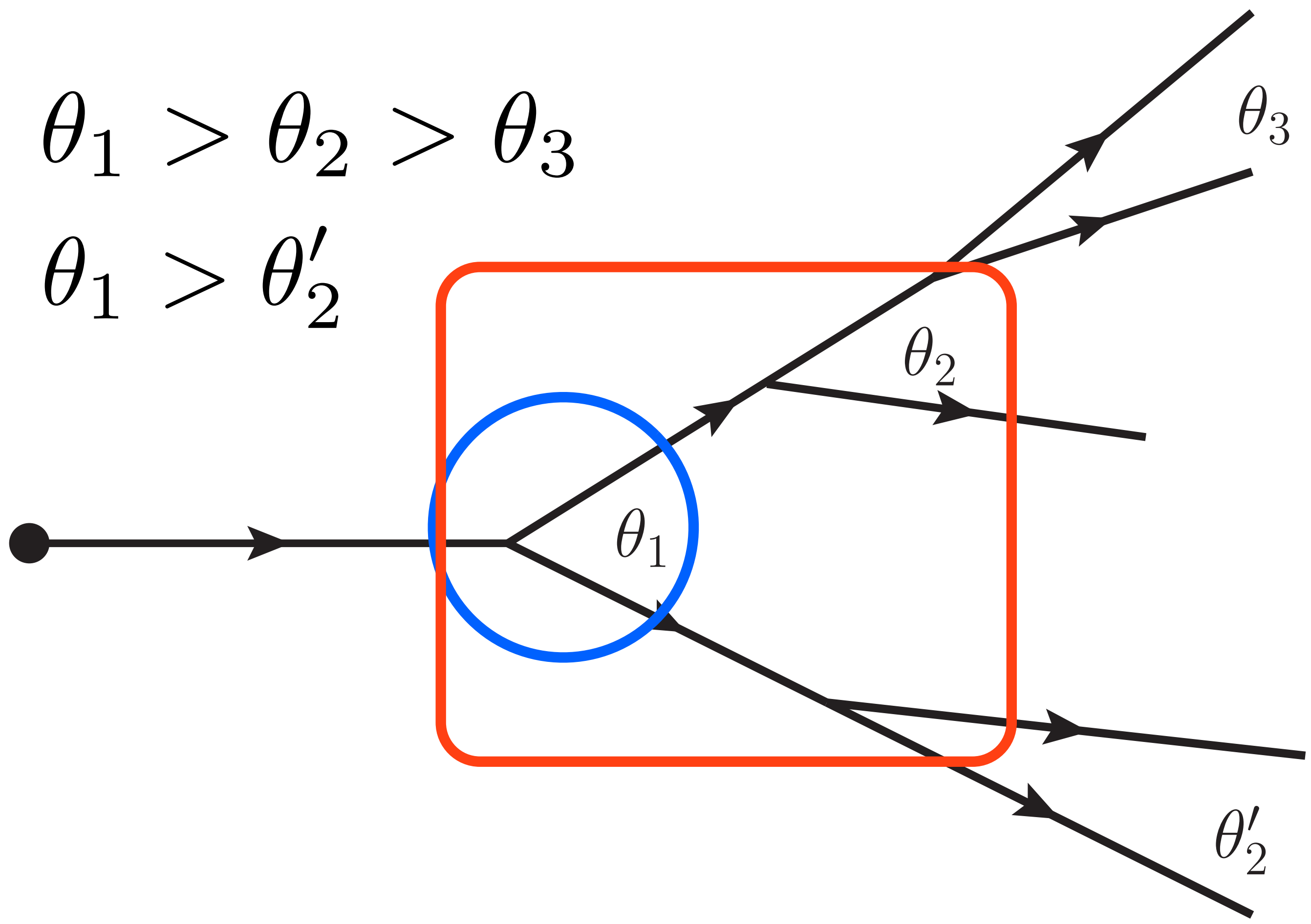
$$\theta_1 > \theta_2 > \theta_3$$

$$\theta_1 > \theta_2'$$



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Markov process!

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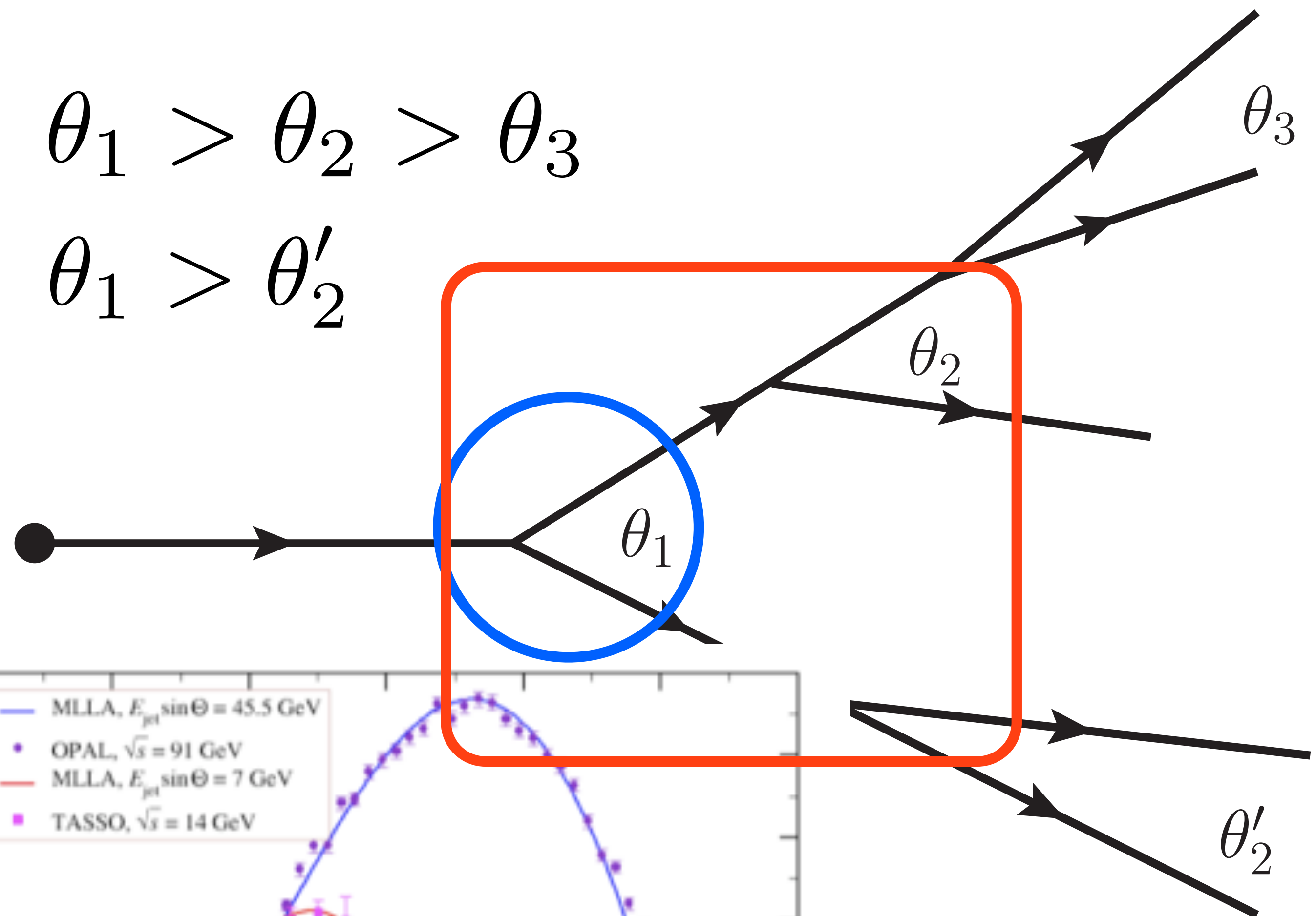
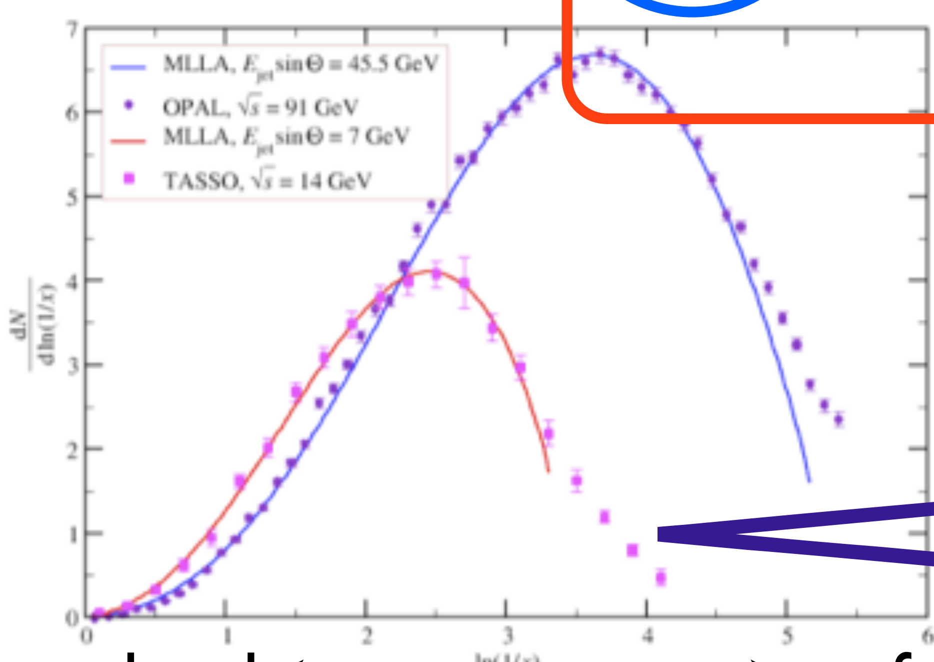




hard ⟷ soft

TASSO Collaboration, Z. Phys. C 47 (1990)
OPAL Collaboration, Phys. Lett. B 247 (1990)

Leading Logarithms

$$dP \propto \frac{\alpha_s C_R}{\pi} \frac{d\omega}{\omega} \frac{d\theta}{\theta}$$

Angular ordering

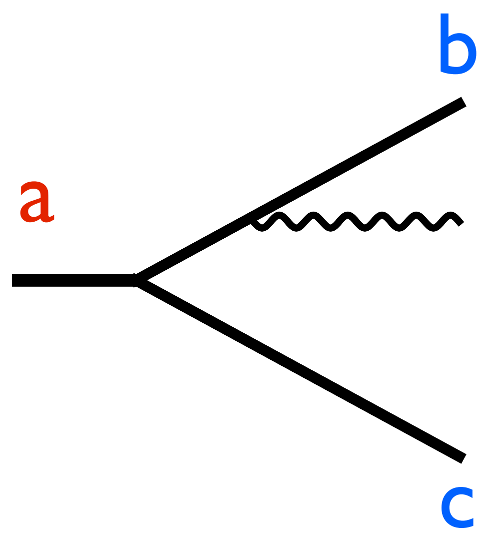
$$d^2P \propto \Theta(\theta_1 - \theta_2)\, dP_1\, dP_2$$

AO limits phase space for soft emissions!

Markov process!

ANTENNA IN VACUUM
(BUILDING BLOCK OF QCD EVOLUTION)

gluon radiation off a pair of color charges b and c which originates from a (highly virtual) charge a



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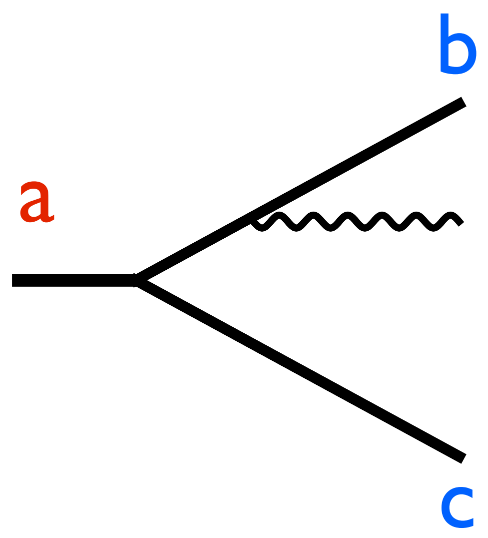

$$(2\pi)^2\,\omega\frac{dN_{\rm a}}{d^3k} = \frac{\alpha_s}{\omega^2}\left[C_{\rm b}\left(\mathcal{R}_{\rm b} - \mathcal{J}\right) + ({\rm b}\to{\rm c}) + C_{\rm a}\,\mathcal{J}\right]$$

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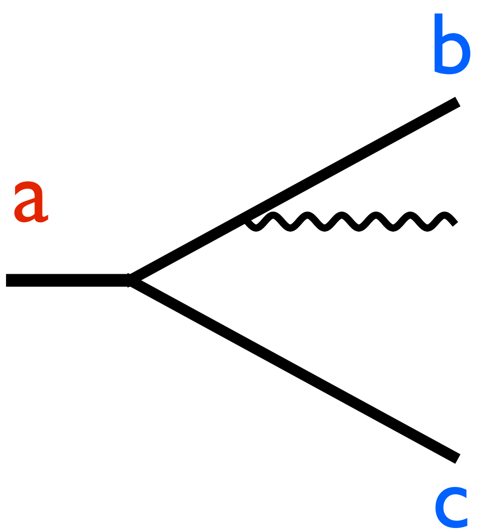

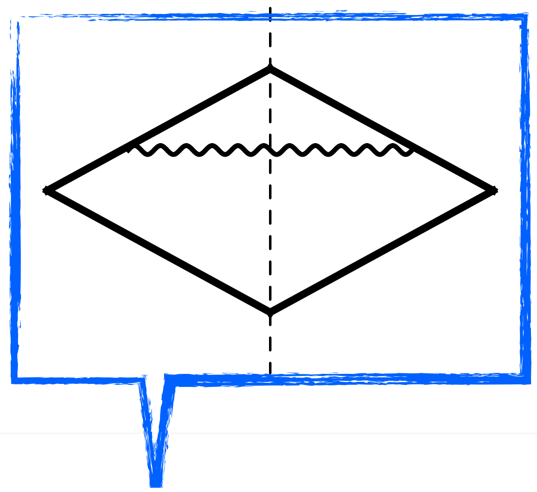

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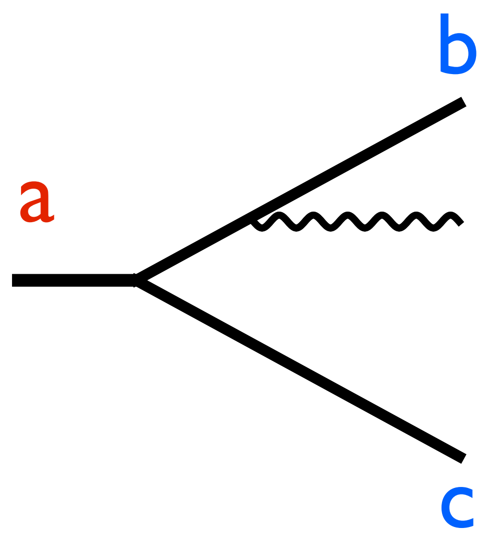

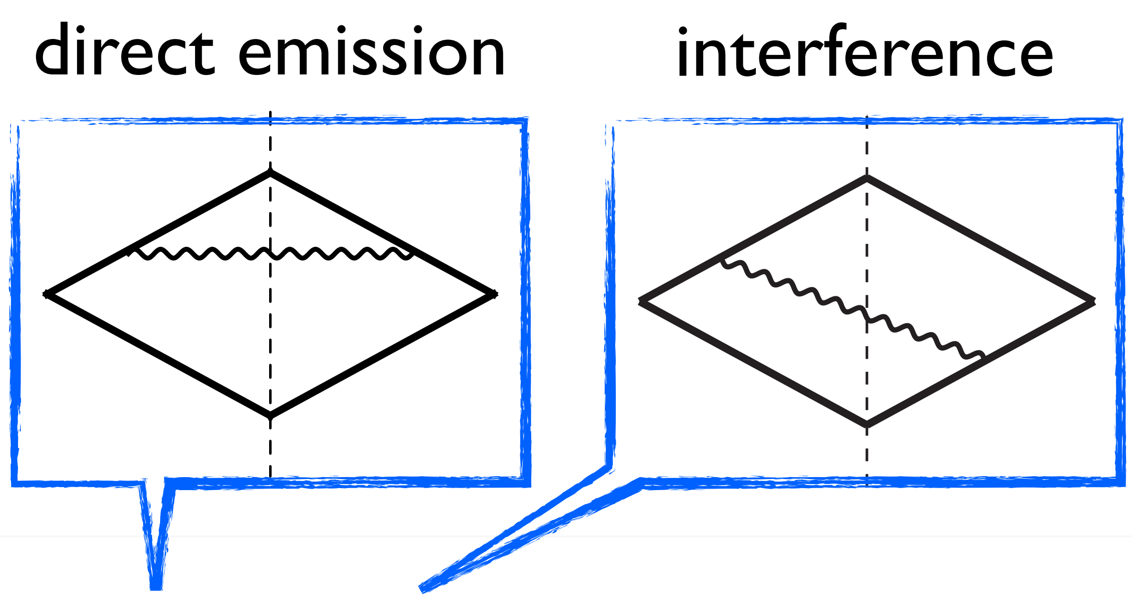

$$(2\pi)^2\,\omega\frac{dN_{\mathrm{a}}}{d^3k} = \frac{\alpha_s}{\omega^2}\left[C_{\mathrm{b}}\left(\mathcal{R}_{\mathrm{b}} - \mathcal{J}\right) + (\mathrm{b} \to \mathrm{c}) + C_{\mathrm{a}}\,\mathcal{J}\right]$$

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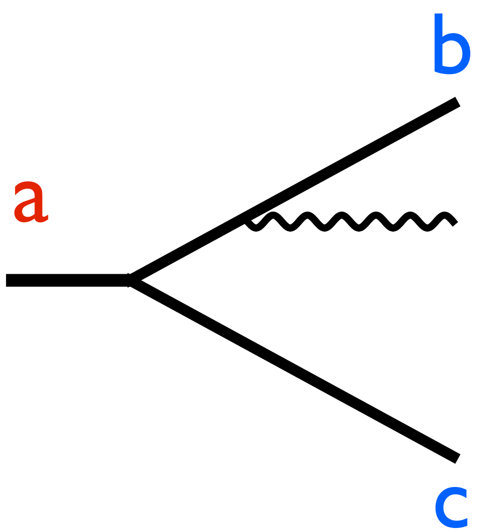

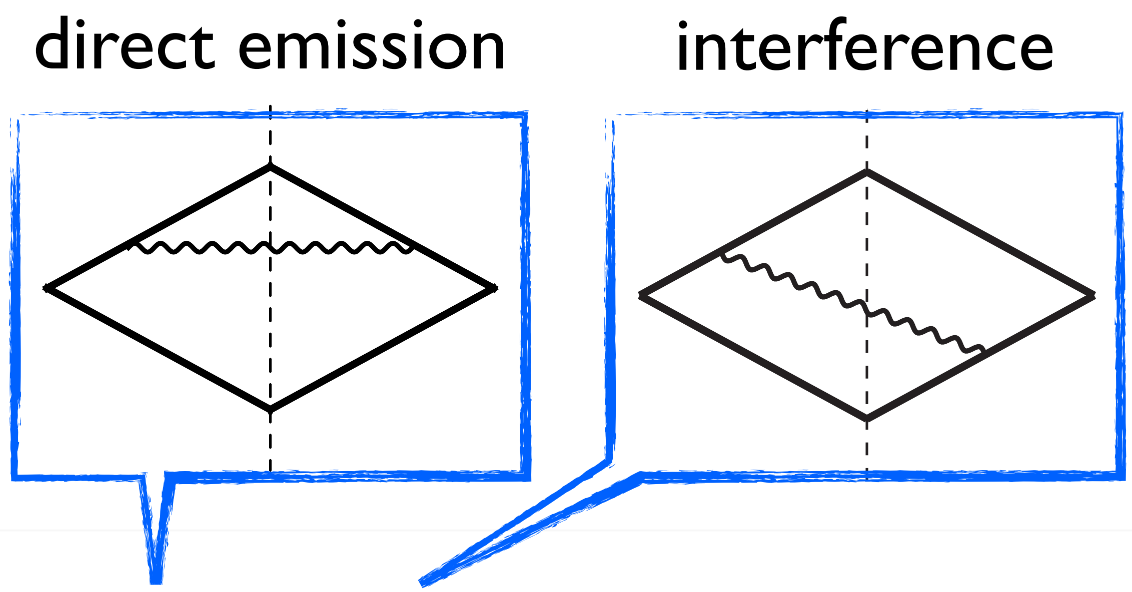

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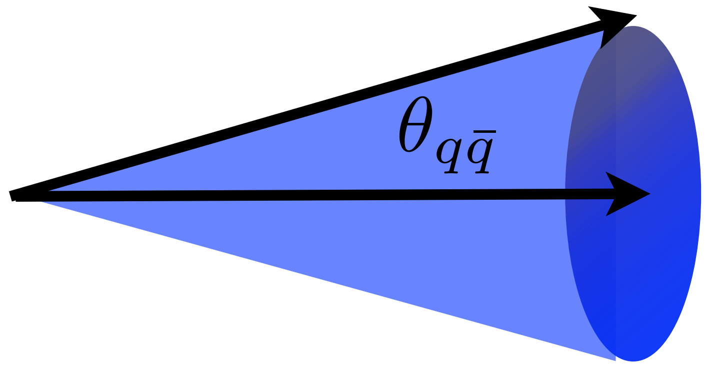
For g→qq $C_\mathrm{b} = C_\mathrm{c} = C_F$ and $C_\mathrm{a} = C_A$

For γ→qq $C_\mathrm{b} = C_\mathrm{c} = C_F$ and $C_\mathrm{a} = 0$

ANTENNA IN VACUUM
(BUILDING BLOCK OF QCD EVOLUTION)

$$dN^{\mathrm{vac}}_{q,\gamma^*} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta}\Theta(\cos\theta - \cos\theta_{q\bar{q}}),$$

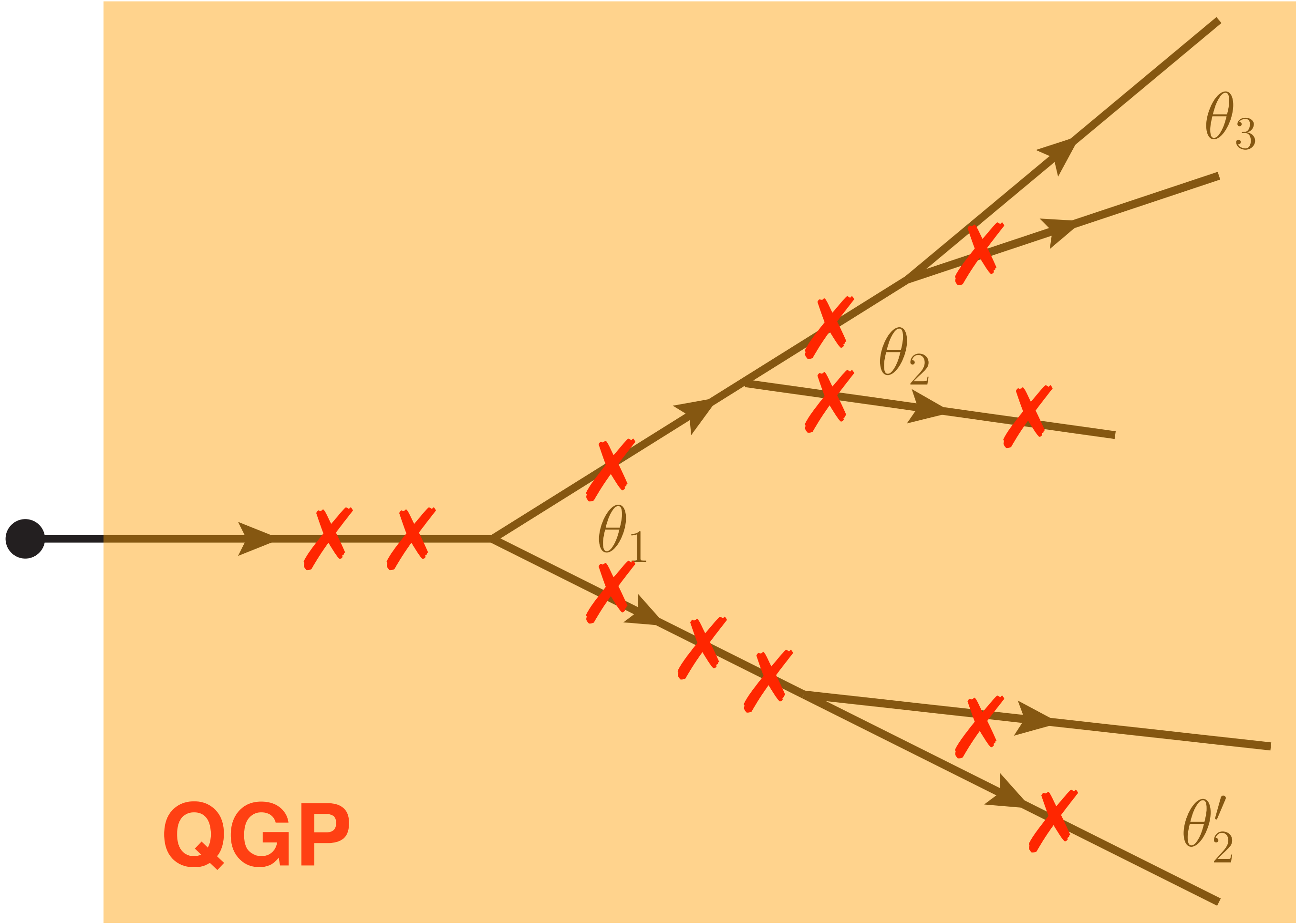


Angular ordering in vacuum

- Radiation confined inside the cone
- Why?

gluons emitted at angles larger than the pair opening angle cannot resolve its internal structure: Emission by the total charge (suppressed for a white antenna)

HOW IS THE JET MODIFIED?



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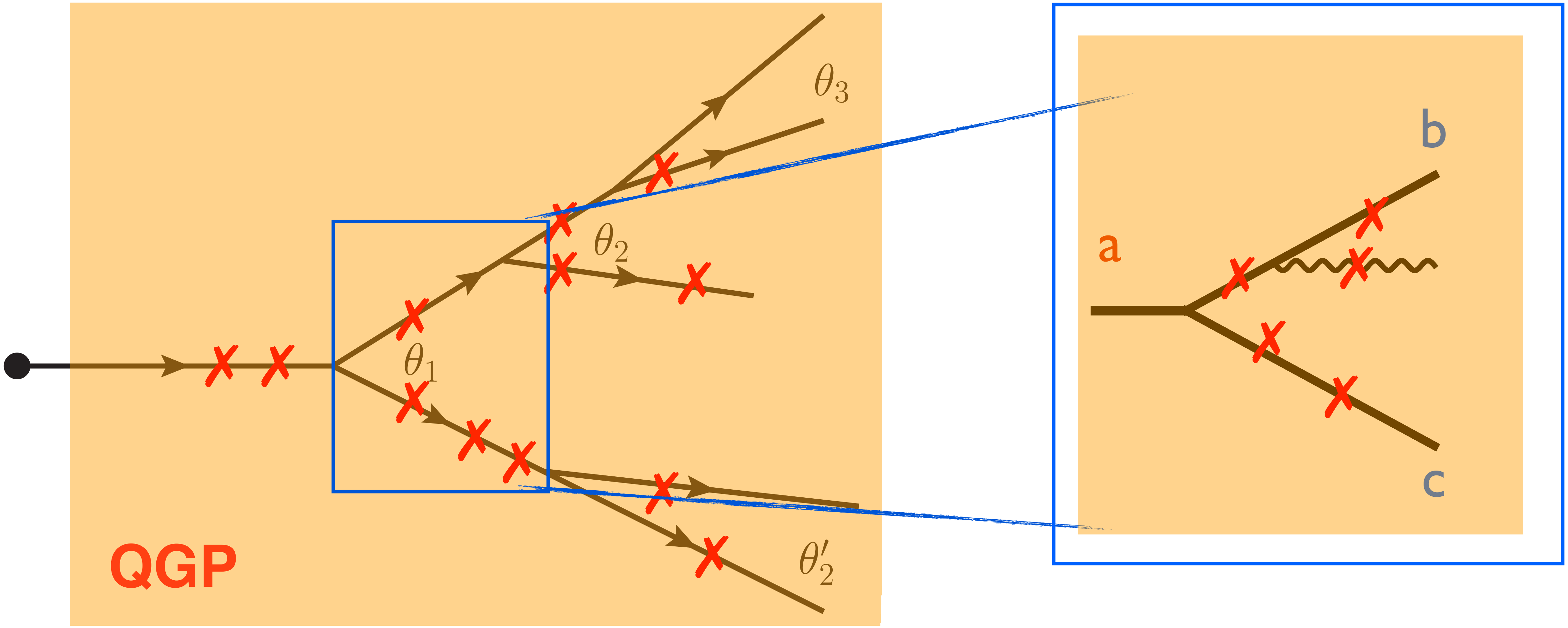

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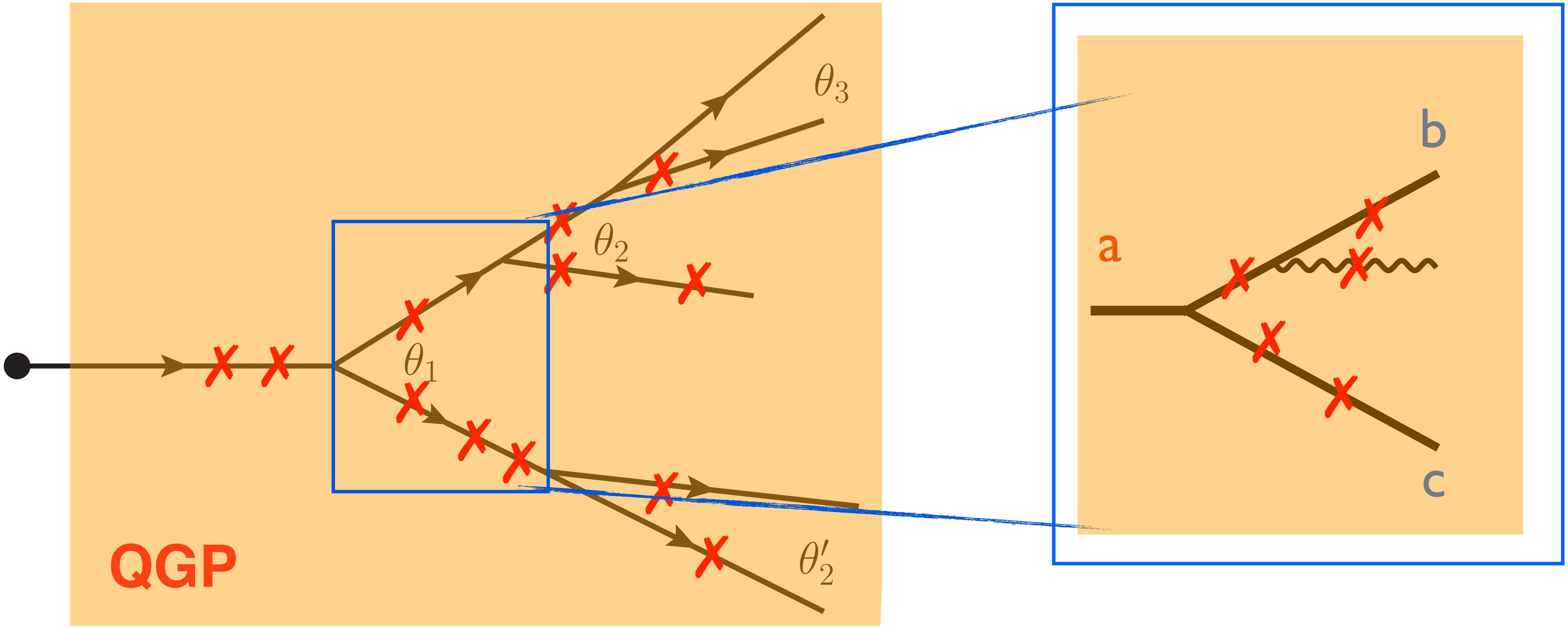


Q: how is the antenna radiation modified in a medium?

Building block of the in-medium cascade

SPACE-TIME STRUCTURE OF IN-MEDIUM INTERFERENCES

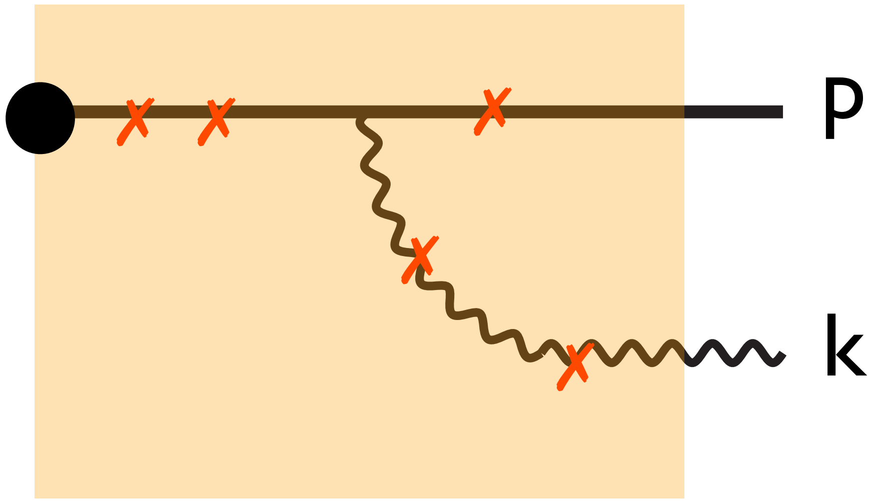
Consider an energetic charge q (eikonal current)

$$J_q(x) = g\, U_p(x^+, 0)\, \delta^{(3)}(\vec{x} - \frac{\vec{p}}{E} t)\Theta(t)\, Q_q$$

Color precession along the trajectory:

$$U_p(x^+, 0) = \mathcal{P}_+ \exp\left\{ ig \int_0^{x^+} dz^+ \left[T \cdot A^-_{\rm med}(z^+, z^+ p_\perp / p^+) \right] \right\}$$

Setup: Solving the linearized Yang-Mills Eqs. for the gluon field

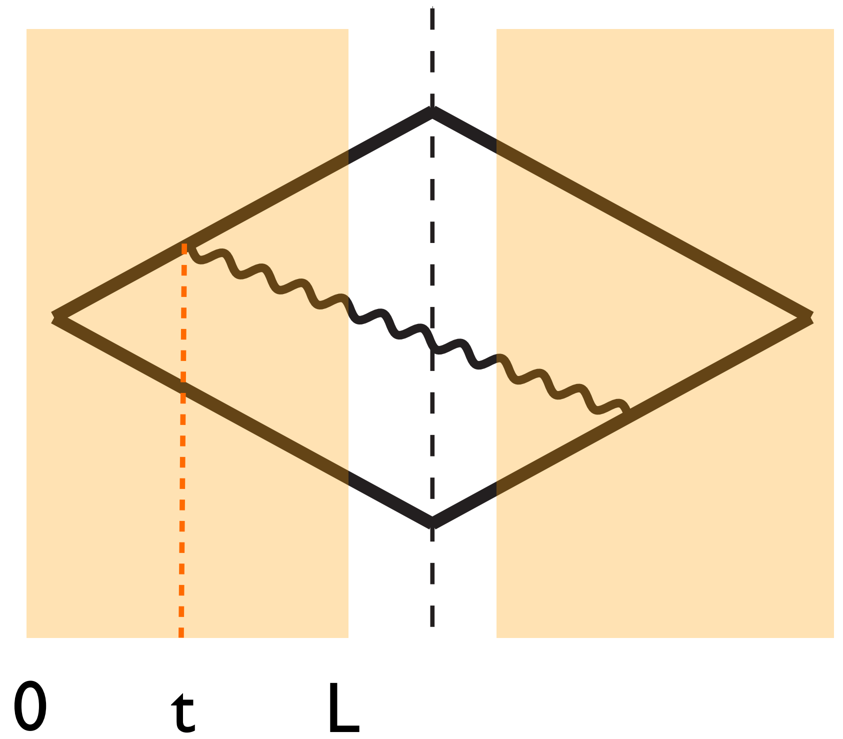


Non-eikonal gluon propagation

SPACE-TIME STRUCTURE OF IN-MEDIUM INTERFERENCES

$\mathcal{R}$: direct emission - BDMPS spectrum - anywhere up to L

$\mathcal{J}$: interferences ⇒



interferences depend on the decoherence parameter

$$\Delta_{\rm med} = 1 - \frac{1}{N_c^2 - 1} \langle \mathbf{Tr}\, U_p(t,0) U_{\bar{p}}^{\dagger}(t,0) \rangle \approx 1 - e^{-\frac{1}{12}\hat{q}\theta^2 t^3}$$

decoherence time

only gluons formed at $t < t_d \equiv (\hat{q}\,\theta_{q\bar{q}}^2)^{-1/3}$ interfere

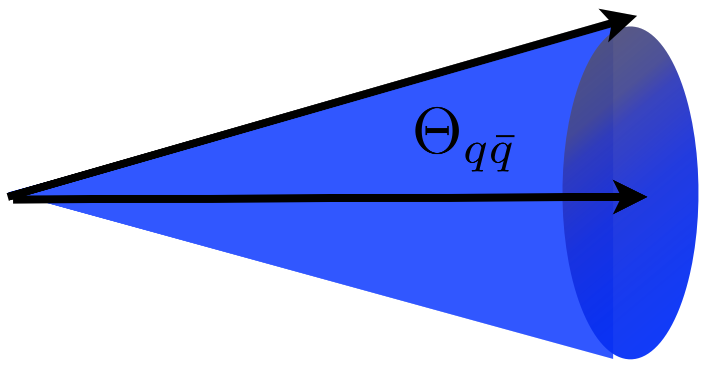
⇒ Suppression of interferences

[Y. M.-T., C.A. Salgado and K. Tywoniuk 2011]
[E. Iancu and J. Casalderray-Solana 2011]

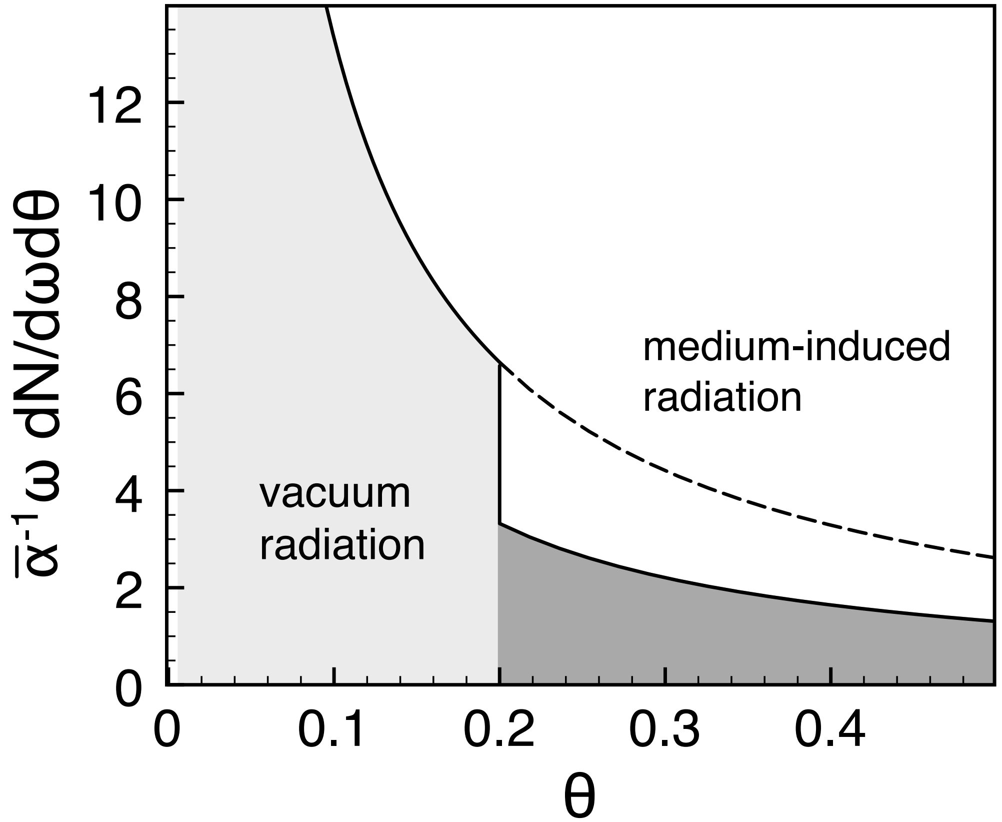
ONSET OF DECOHERENCE - SOFT GLUONS

$$\Delta_{\rm med} \equiv \Delta_{\rm med}(L)$$

$\Delta_{\rm med} \to 0$ Coherence



$$dN^{\rm tot}_{q,\gamma^*} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta}\left[\Theta(\cos\theta-\cos\theta_{q\bar{q}})+\Delta_{\rm med}\,\Theta(\cos\theta_{q\bar{q}}-\cos\theta)\right] \ .$$



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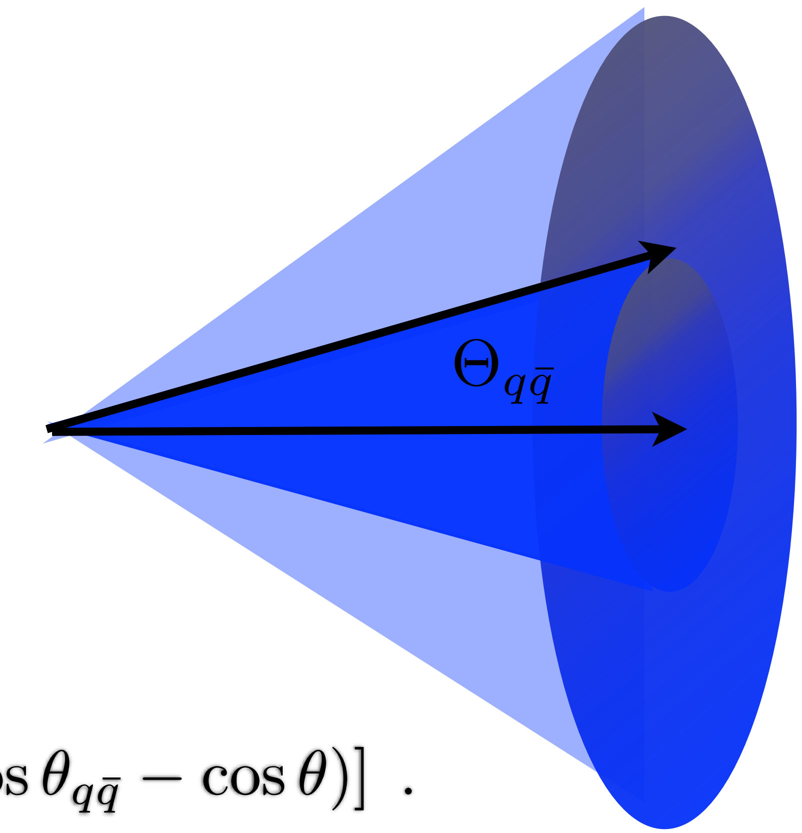
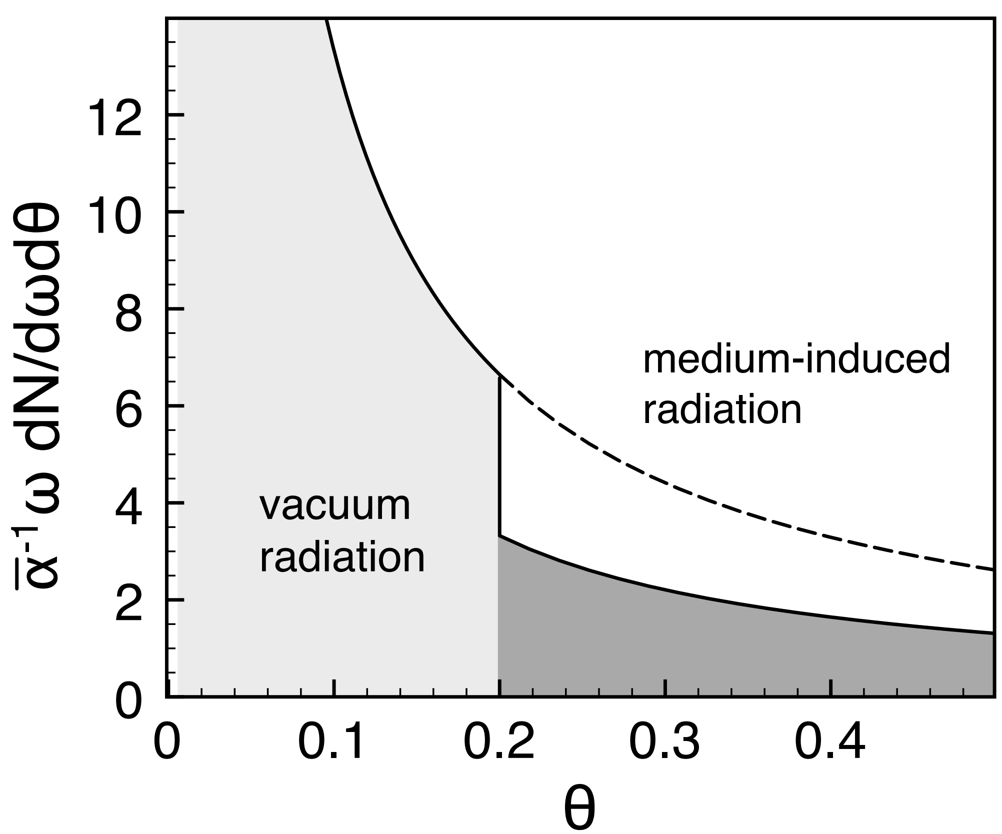


$\Delta_{\rm med} \to 0$ Coherence

$\Delta_{\rm med} \to 1$ Decoherence

$$dN^{\rm tot}_{q,\gamma^*} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta}\left[\Theta(\cos\theta-\cos\theta_{q\bar{q}})+\Delta_{\rm med}\,\Theta(\cos\theta_{q\bar{q}}-\cos\theta)\right] .$$



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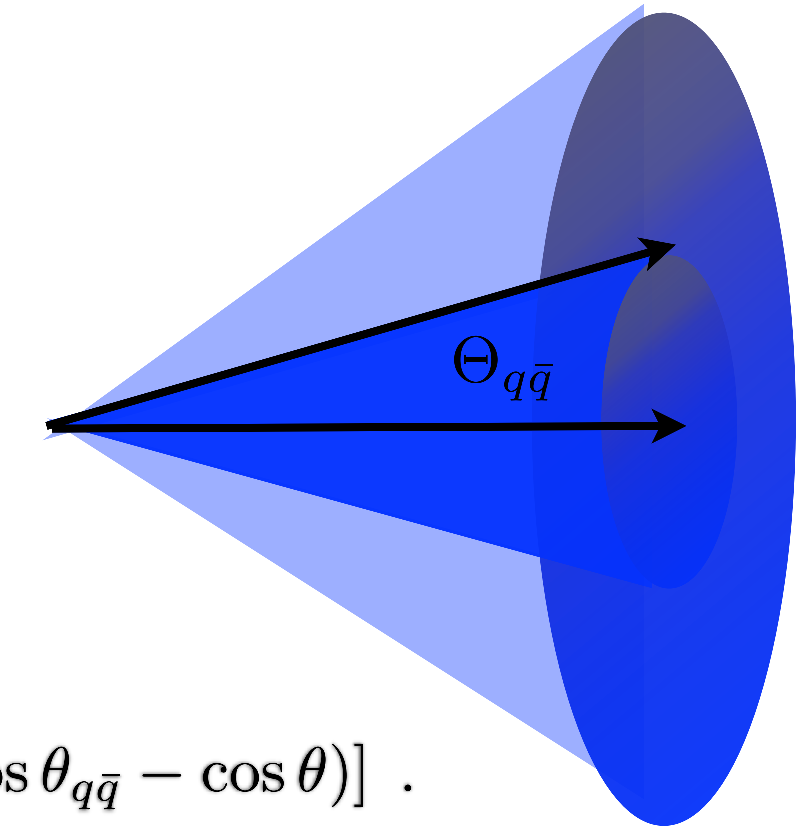
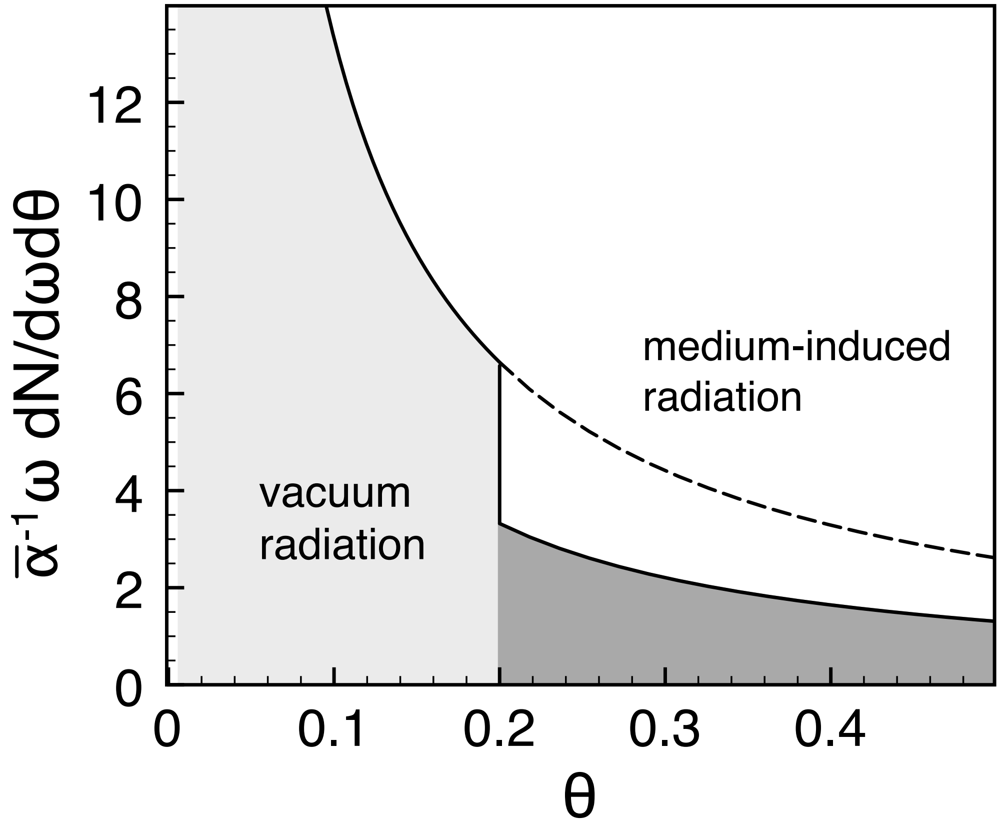


$$dN^{\rm tot}_{q,\gamma^*} = \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{\sin\theta\ d\theta}{1-\cos\theta} \left[\Theta(\cos\theta - \cos\theta_{q\bar{q}}) + \Delta_{\rm med}\,\Theta(\cos\theta_{q\bar{q}} - \cos\theta)\right] \ .$$

⇒ geometrical separation!



ONSET OF DECOHERENCE - SOFT GLUONS

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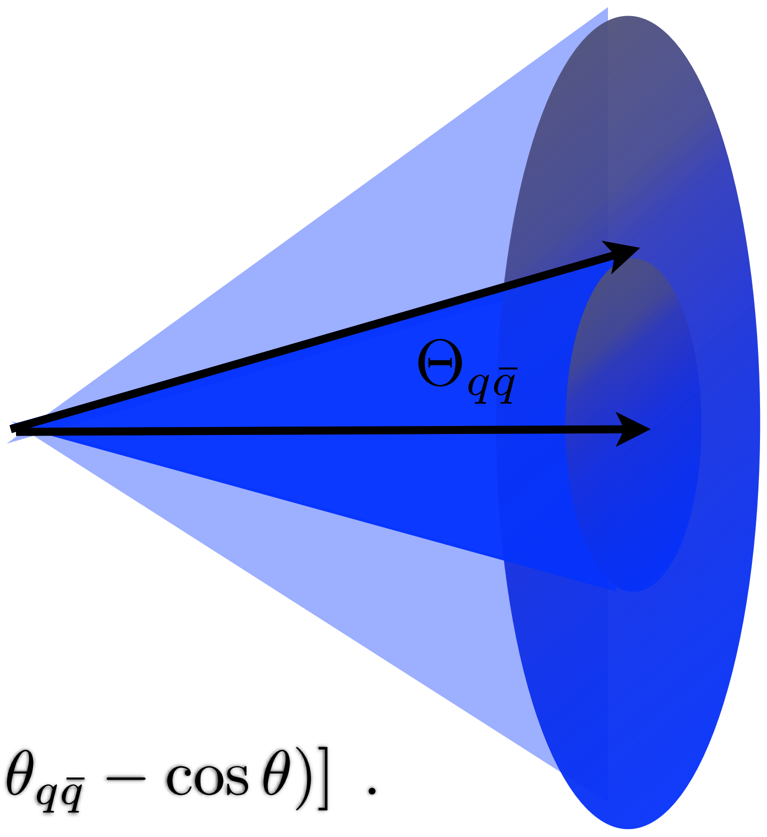
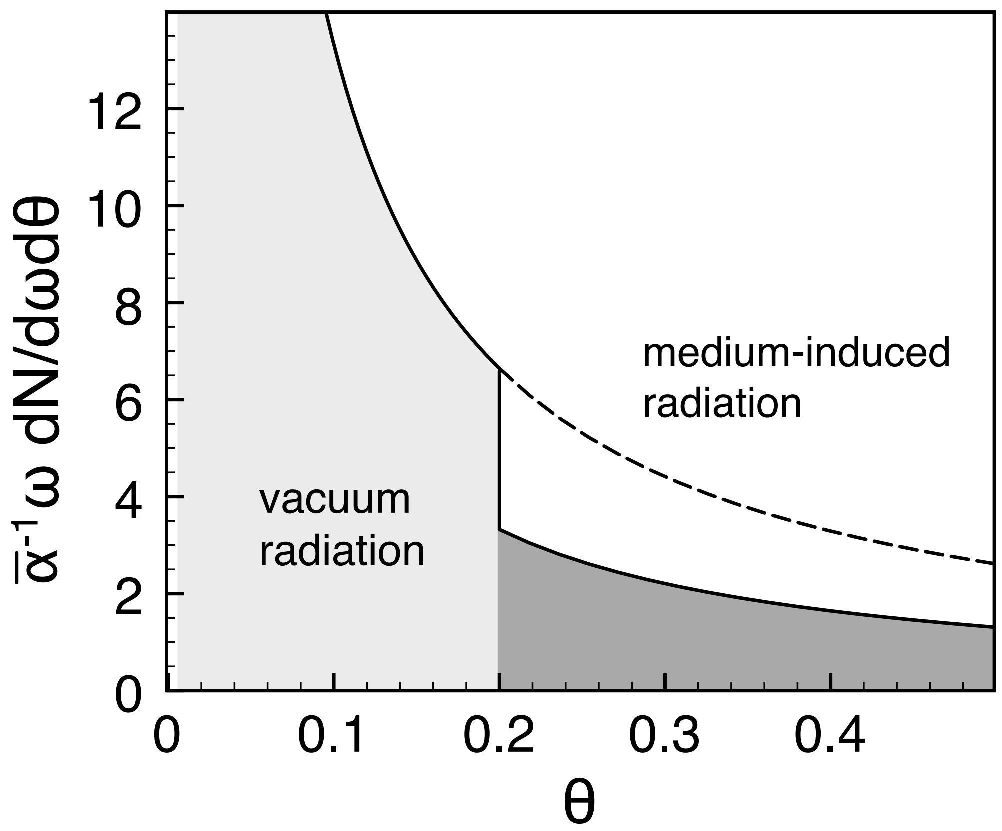


$$dN^{\text{tot}}_{q,\gamma^*} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta}\left[\Theta(\cos\theta - \cos\theta_{q\bar{q}}) + \Delta_{\text{med}}\,\Theta(\cos\theta_{q\bar{q}} - \cos\theta)\right] .$$

⇒ geometrical separation!

$$dN^{\text{tot}}_{q,\gamma^*}\Big|_{\text{opaque}} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta} .$$



1) Independent emissions!

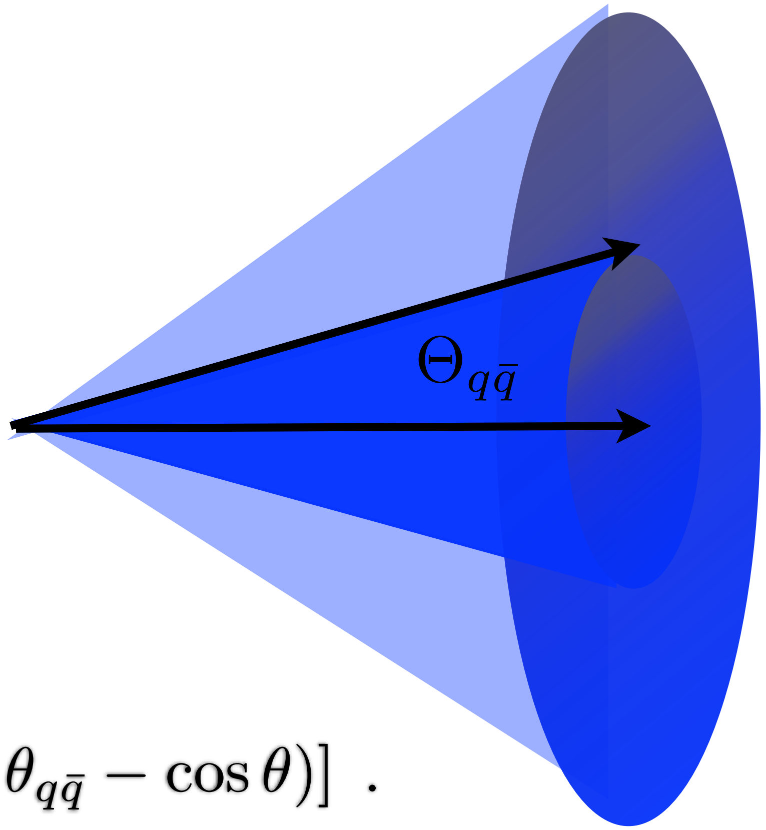
2) “Memory loss” effect

ONSET OF DECOHERENCE - SOFT GLUONS

$\Delta_{\rm med} \equiv \Delta_{\rm med}(L)$

$\Delta_{\rm med} \to 0$ Coherence

$\Delta_{\rm med} \to 1$ Decoherence



$$dN^{\rm tot}_{q,\gamma^*} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta}\left[\Theta(\cos\theta - \cos\theta_{q\bar{q}}) + \Delta_{\rm med}\,\Theta(\cos\theta_{q\bar{q}} - \cos\theta)\right] \,.$$

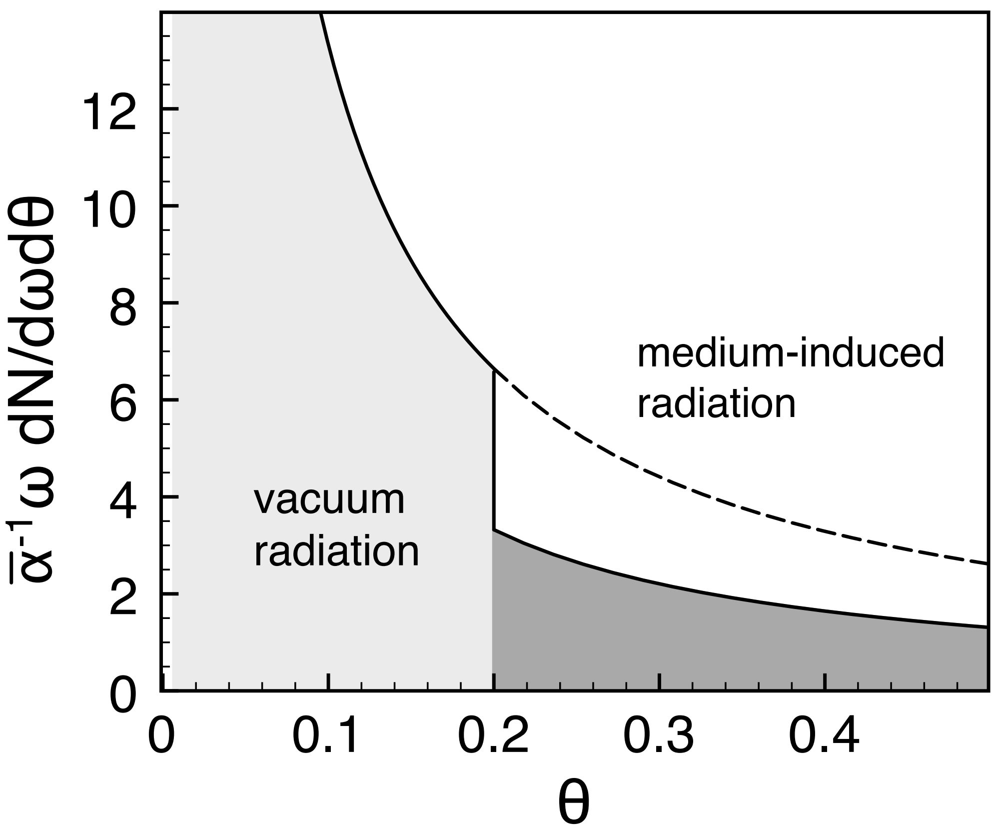
⇒ geometrical separation!

$$dN^{\rm tot}_{q,\gamma^*}\Big|_{\rm opaque} = \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{\sin\theta\ d\theta}{1-\cos\theta} \,.$$

and gluon!

1) Independent emissions!

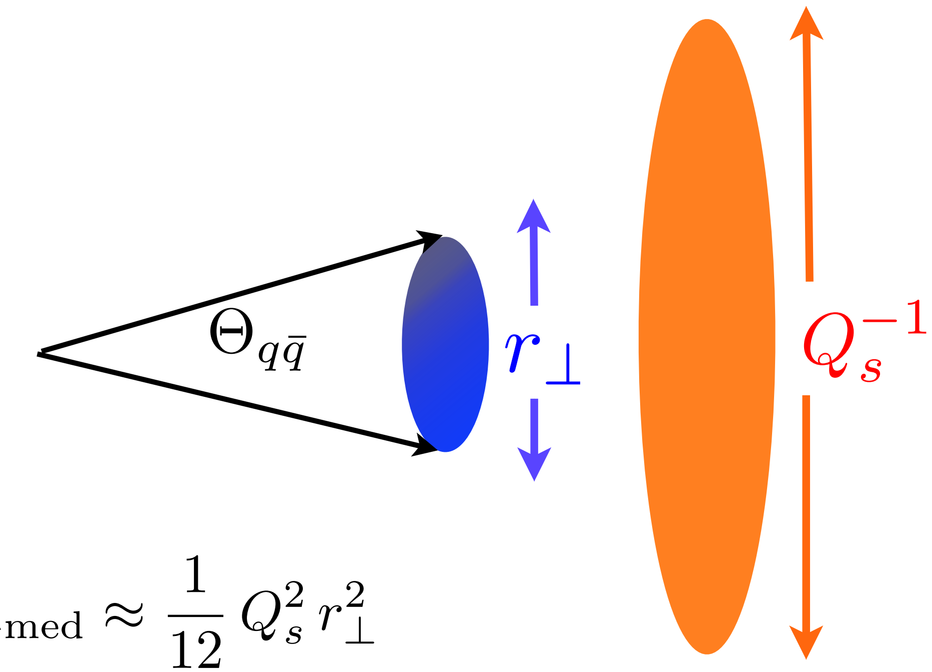
2) “Memory loss” effect



HARD SCALES IN THE PROBLEM

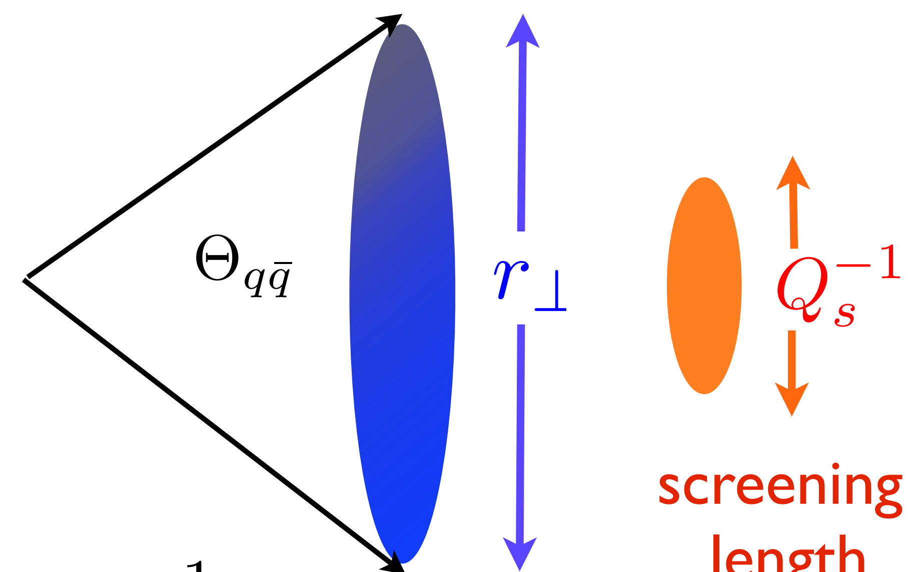
$Q_s^2 = \hat{q}\, L$ $\quad$ $r_\perp = \theta_{q\bar{q}}\, L$ $\quad$ - a two scale problem!

- $r_\perp < Q_s^{-1}$ (Dipole regime)



$\Delta_{\text{med}} \approx \frac{1}{12}\, Q_s^2\, r_\perp^2$

- $r_\perp > Q_s^{-1}$ (Decoh. regime)



$\Delta_{\text{med}} \approx 1$

$\tau_d = \left(\hat{q}\theta_{q\bar{q}}^2\right)^{-1/3}$

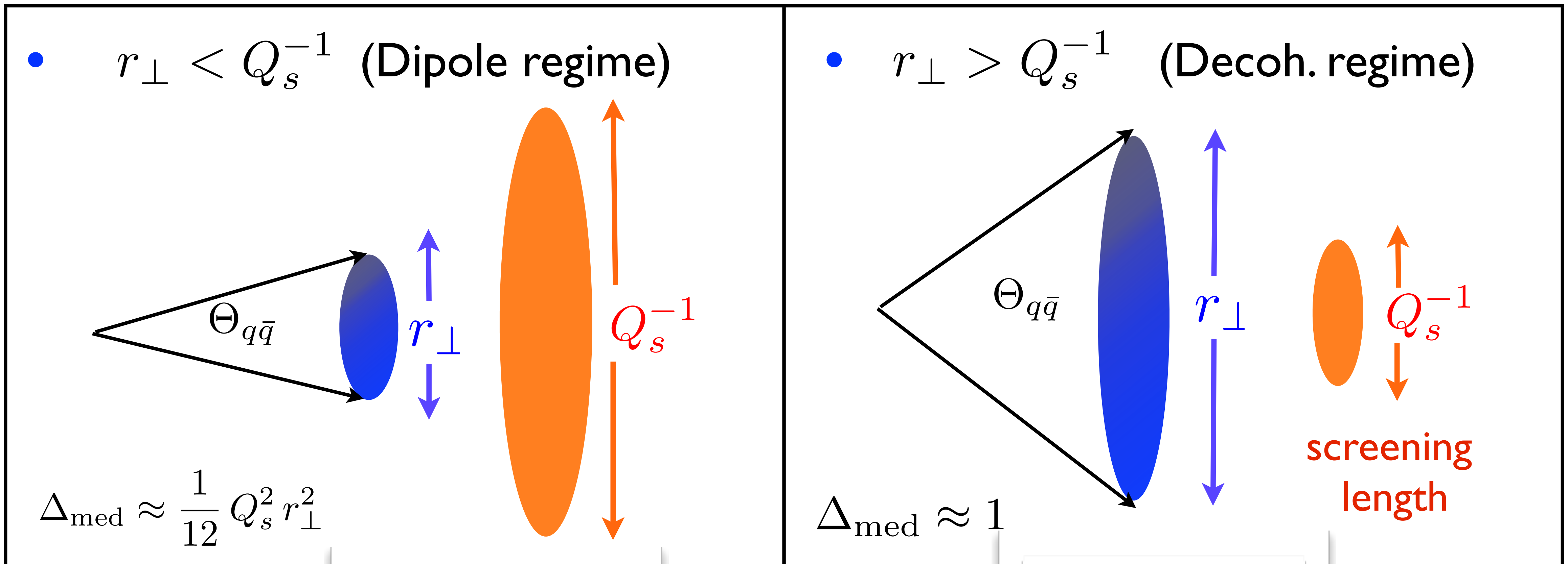
$$\Delta_{\text{med}} \approx 1 - \exp[-\frac{1}{12}\, Q_s^2\, r_\perp^2]$$

$r_\perp = \theta_{q\bar{q}} L$

Qs: characteristic momentum scale of the medium

HARD SCALES IN THE PROBLEM

$Q_s^2 = \hat{q}\, L$ $\quad$ $r_\perp = \theta_{q\bar{q}}\, L$ $\quad$ **- a two scale problem!**



$\tau_d = \left(\hat{q}\theta_{q\bar{q}}^2\right)^{-1/3}$

$$\tau_d \gg L$$

$$\tau_d \ll L$$

$r_\perp =$

$$\Delta_{\rm med} \approx 1 - \exp[-\frac{1}{12}\, Q_s^2\, r_\perp^2]$$

Q_s: characteristic momentum scale of the medium

HARD SCALES IN THE PROBLEM

Gluon spectrum characterized by the hardest scale in the problem

$$Q_{\rm hard} = \max\left(r_\perp^{-1}, Q_s\right)$$

$$Q_s^2 = \hat{q}\, L \qquad\qquad r_\perp = \theta_{q\bar{q}}\, L$$

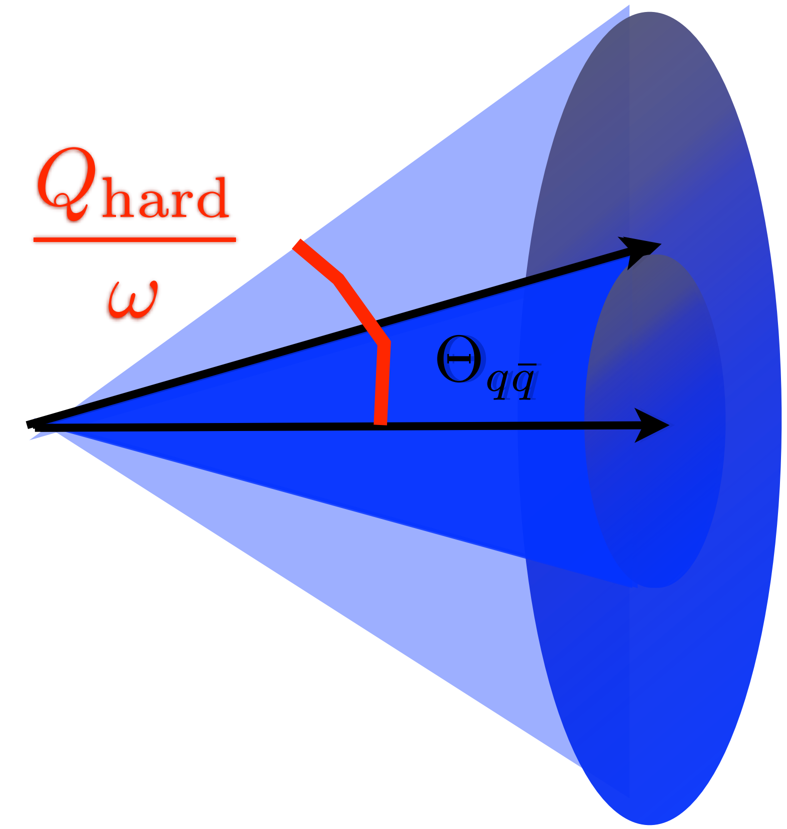
medium-induced color randomization destroys the coherence of the antenna and opens up phase space for gluon radiation up to

for gluon momentum $k_\perp > Q_{\rm hard}$ the spectrum is suppressed and coherence is restored

✓ The system cannot induced radiations harder than the intrinsic scales of the problem

ONSET OF DECOHERENCE - FINITE GLUON ENERGIES

$$Q_{\rm hard} = \max\left(r_\perp^{-1}, Q_s\right)$$



In terms of angular variables:

Vacuum: Independent emissions for $\theta < \theta_{q\bar{q}}$
Emission off the total charge otherwise (coherence)

Full decoherence: Independent emissions for $\theta < \theta_{\rm med} = \frac{Q_s}{\omega}$
Emission off the total charge otherwise (coherence)

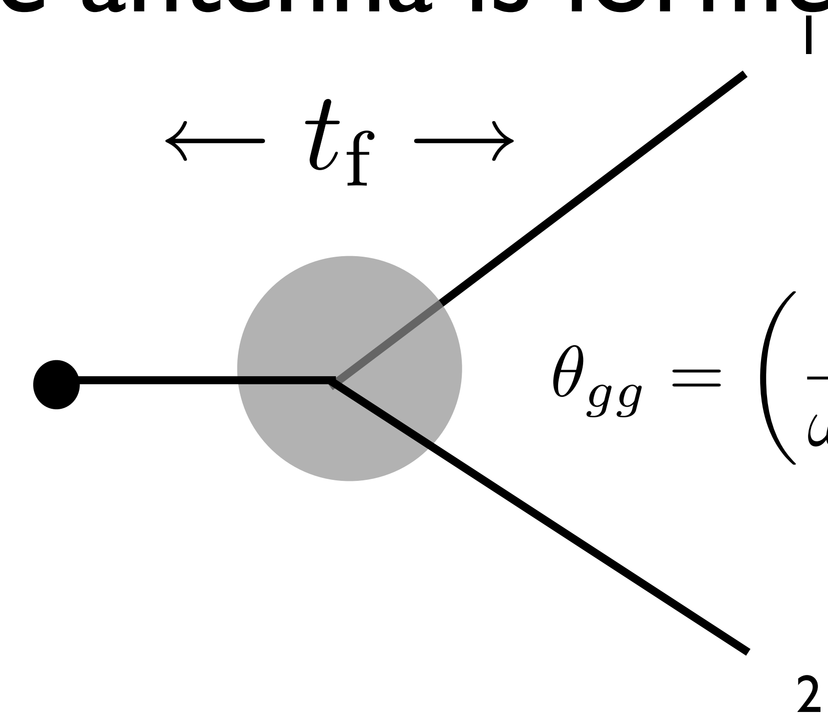
⇒ In the opaque limit, simple shift of the angular constraint!

DECOHERENCE OF MULTI-GLUON EMISSIONS

Baier, Dokshitzer, Mueller, Peigné, Schiff (1995-2000) Zakharov (1996)

$$\omega \frac{dN}{d\omega} = \frac{C_F \alpha_s}{\pi} \sqrt{\frac{\hat{q} L^2}{\omega}} \propto \alpha_s \frac{L}{t_\mathrm{f}}$$

The antenna is formed in the medium



$$\longleftarrow t_\mathrm{f} \longrightarrow$$

$$\theta_{gg} = \left(\frac{\hat{q}}{\omega^3} \right)^{1/4}$$

formation time

$$t_\mathrm{f} = \sqrt{\frac{\omega}{\hat{q}}}$$

Emission time

$$t \sim L \gg t_\mathrm{f}$$

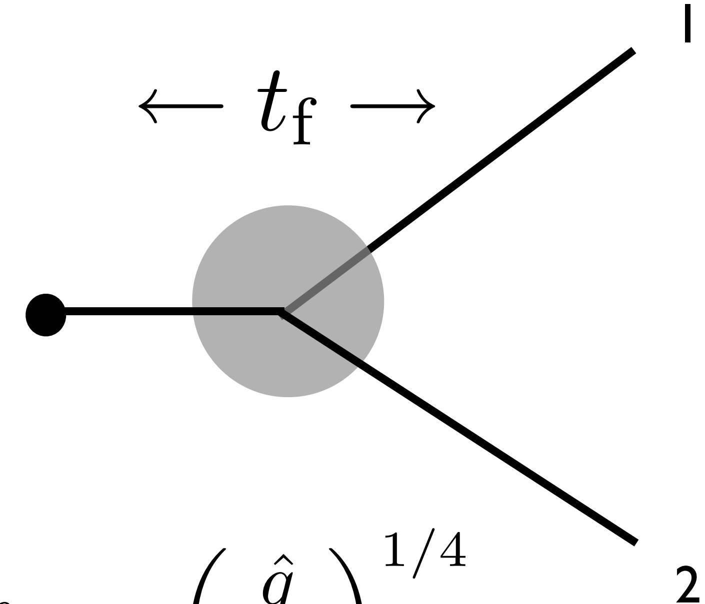
DECOHERENCE OF MULTI-GLUON EMISSIONS

decoherence time

$$t_{\mathrm{d}} = (\hat{q}\,\theta_{gg}^2)^{-1/3}$$

formation time

$$t_{\mathrm{f}} = \sqrt{\frac{\omega}{\hat{q}}}$$

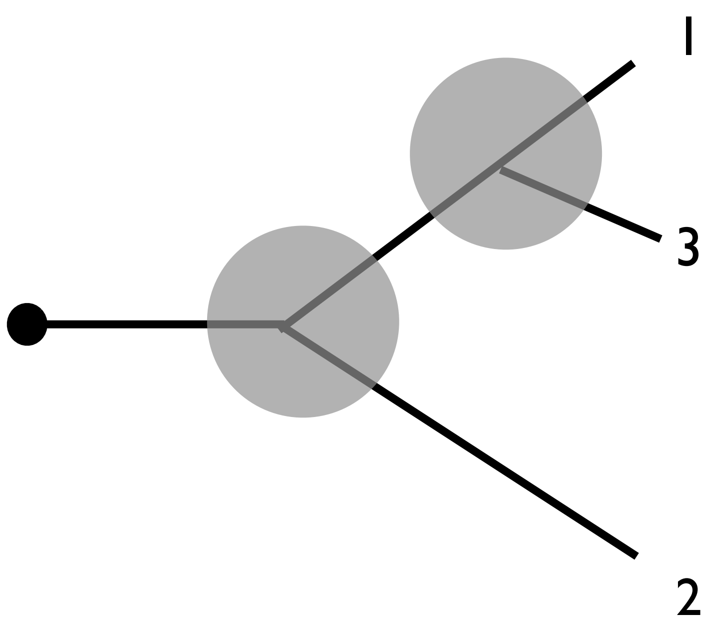


typical angle for medium-induced gluon

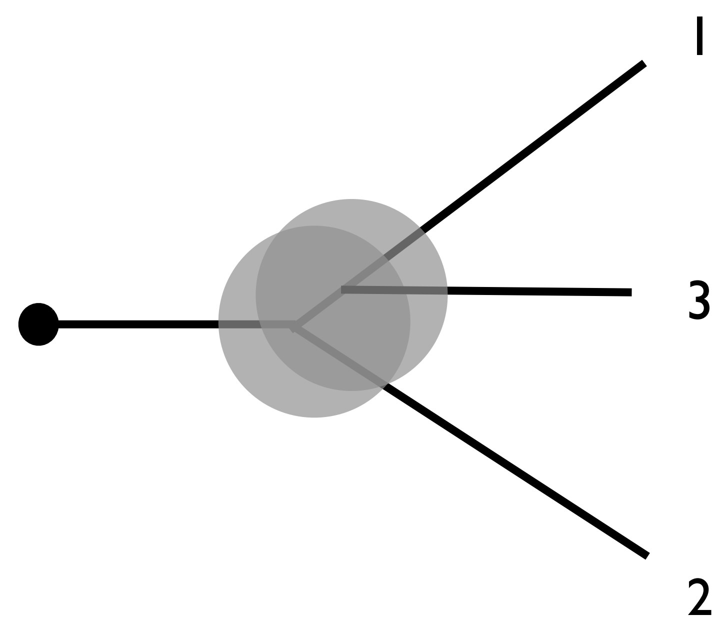
$$\theta_{gg} = \left(\frac{\hat{q}}{\omega^3}\right)^{1/4}$$

$$t_{\mathrm{d}} \equiv t_{\mathrm{f}}$$

(see F. Dominguez 's talk)



incoherent emissions



coherent emissions

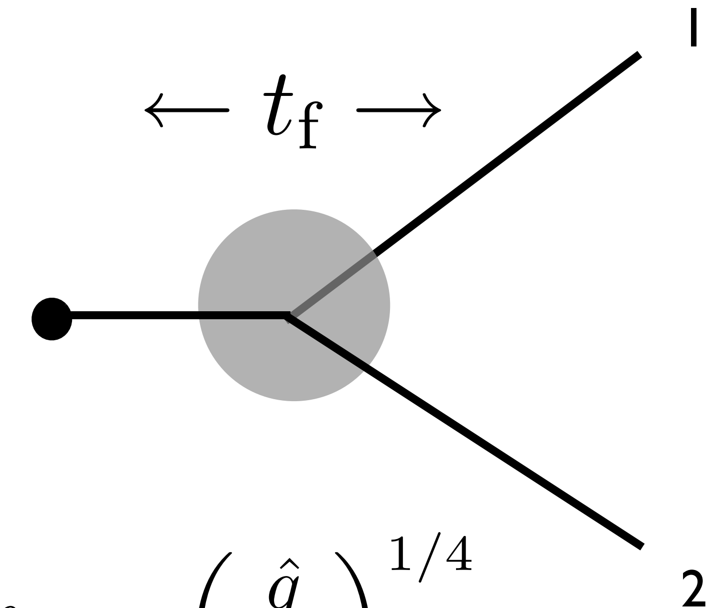
DECOHERENCE OF MULTI-GLUON EMISSIONS

decoherence time

$$t_{\rm d} = (\hat{q}\,\theta_{gg}^2)^{-1/3}$$

formation time

$$t_{\rm f} = \sqrt{\frac{\omega}{\hat{q}}}$$

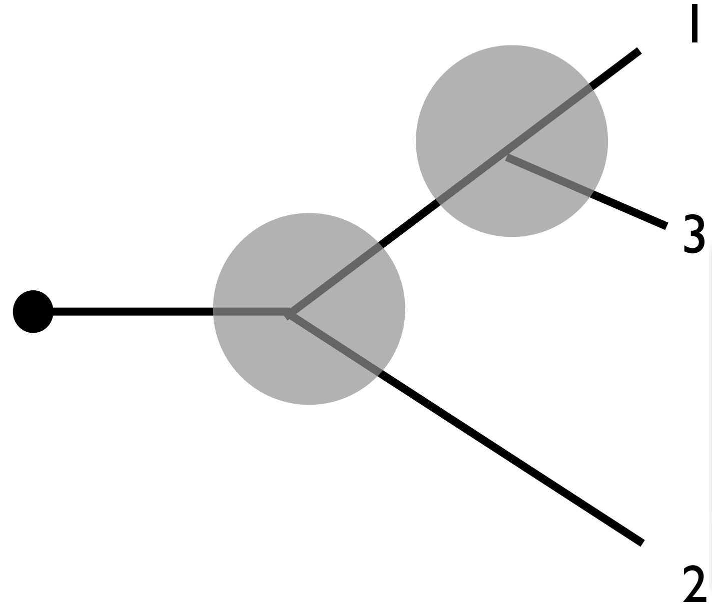


typical angle for medium-induced gluon

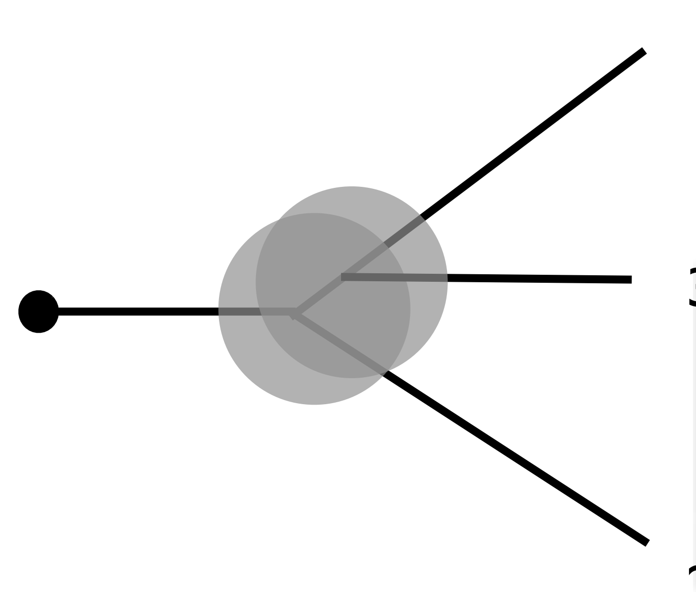
$$\theta_{gg} = \left(\frac{\hat{q}}{\omega^3}\right)^{1/4}$$

$$t_{\rm d} \equiv t_{\rm f}$$

(see F. Dominguez 's talk)



$$\propto \left(\alpha_s \frac{L}{t_{\rm f}}\right)^2$$



$$\propto \alpha_s \left(\alpha_s \frac{L}{t_{\rm t}}\right)$$

incoherent emissions

coherent emissions

SUMMARY

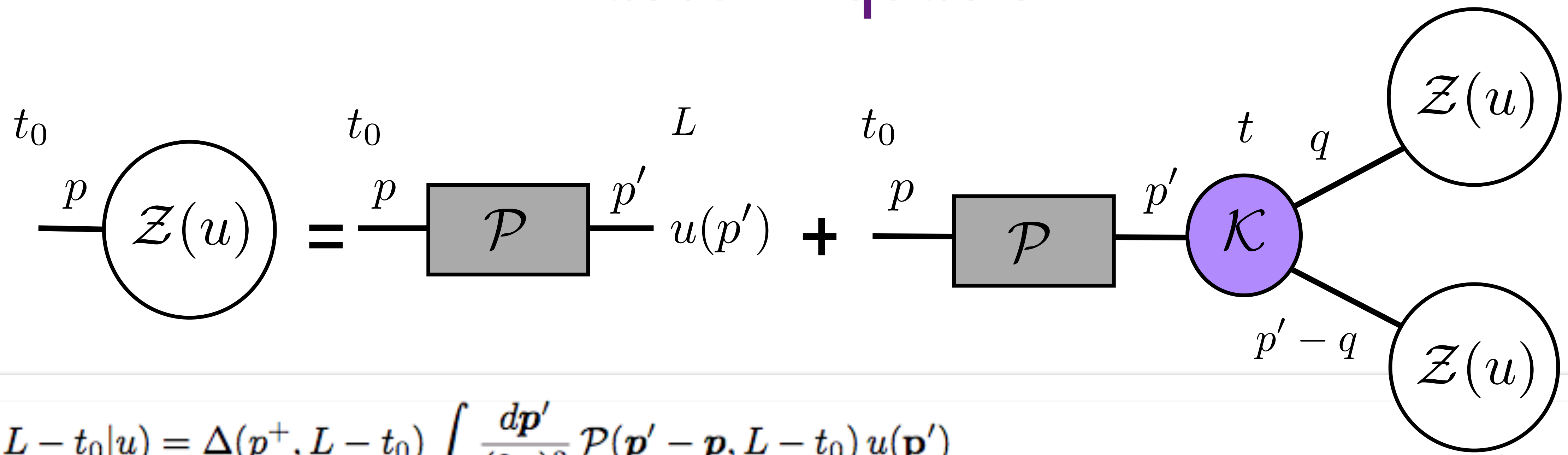
✓ In the limit of a dense medium, parton branchings decohere due to rapid color randomization

✓ A two scale problem: the hardest scale sets the transition from incoherent emissions to coherent emissions

✦ Interplay decoherence ($k_\perp < Q_{hard}$) vs coherence ($k_\perp > Q_{hard}$)

✓ Building block of jet calculus? Probabilistic picture?

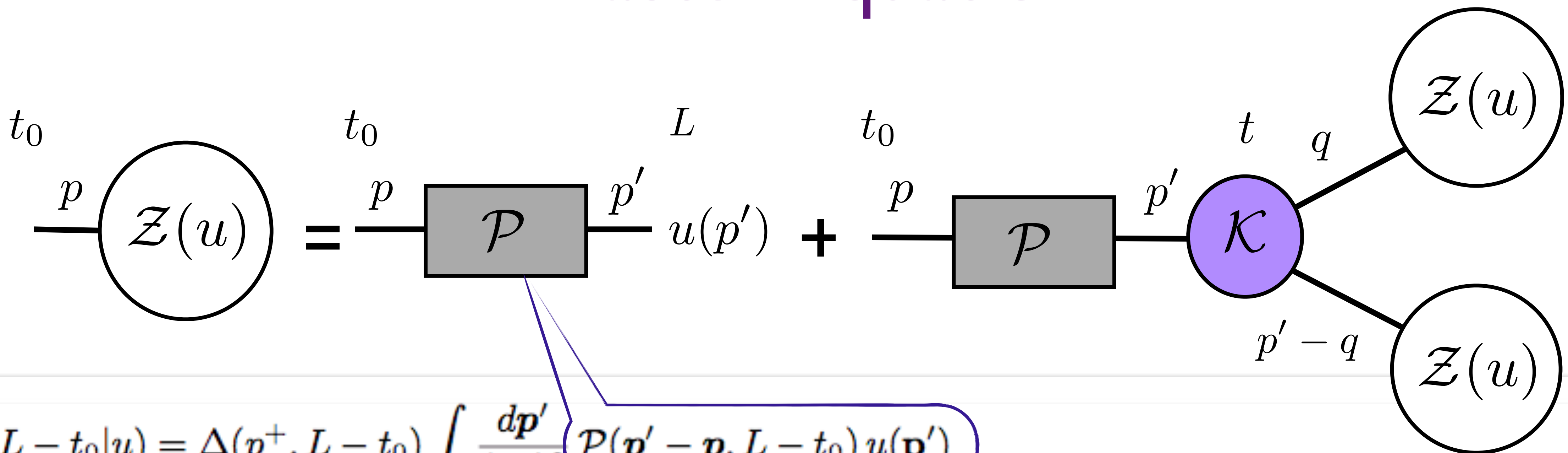
Master Equation



$$\mathcal{Z}(\mathbf{p}, L-t_0|u) = \Delta(p^+, L-t_0)\int \frac{d\boldsymbol{p}'}{(2\pi)^2}\,\mathcal{P}(\boldsymbol{p}'-\boldsymbol{p}, L-t_0)\,u(\mathbf{p}')$$

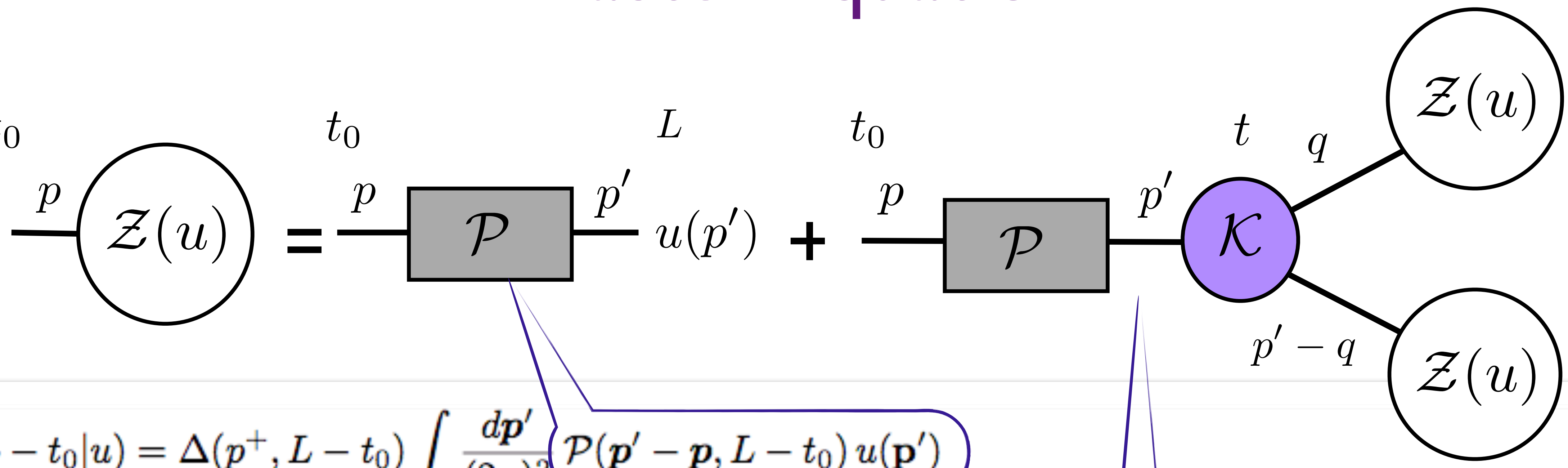
$$+\alpha_s\int_{t_0}^{L} dt\,\Delta(p^+, t-t_0)\int_0^1\frac{dz}{z}\int\frac{d\boldsymbol{p}'}{(2\pi)^2}\mathcal{P}(\boldsymbol{p}'-\boldsymbol{p}, L-t_0)\int\frac{d\boldsymbol{q}}{(2\pi)^2}\,\mathcal{K}(\boldsymbol{q}-z\boldsymbol{p}'|z)\,\mathcal{Z}(\mathbf{q}, L-t|u)\,\mathcal{Z}(\mathbf{p}'-\mathbf{q}, L-t|u)$$

Master Equation



$$\mathcal{Z}(\mathbf{p}, L-t_0|u) = \Delta(p^+, L-t_0) \int \frac{d\mathbf{p}'}{(2\pi)^2} \mathcal{P}(\mathbf{p}'-\mathbf{p}, L-t_0)\, u(\mathbf{p}')$$
$$+\alpha_s \int_{t_0}^{L} dt\, \Delta(p^+, t-t_0) \int_0^1 \frac{dz}{z} \int \frac{d\mathbf{p}'}{(2\pi)^2} \mathcal{P}(\mathbf{p}'-\mathbf{p}, L-t_0) \int \frac{d\mathbf{q}}{(2\pi)^2} \mathcal{K}(\mathbf{q}-z\mathbf{p}'|z)\, \mathcal{Z}(\mathbf{q}, L-t|u)\, \mathcal{Z}(\mathbf{p}'-\mathbf{q}, L-t|u)$$

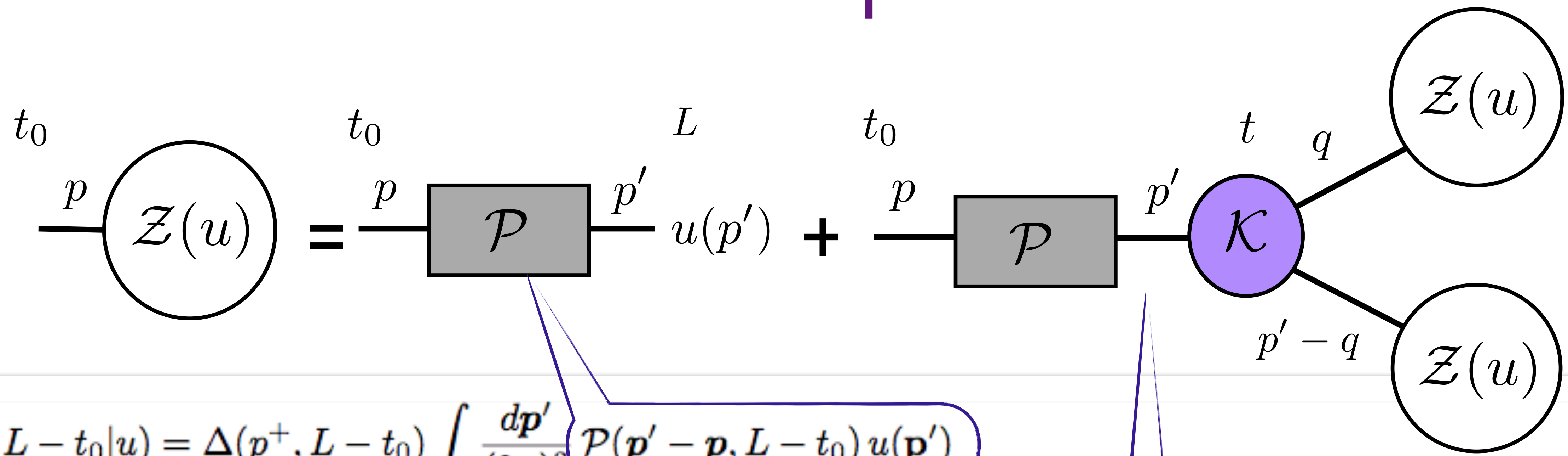
Master Equation



$$\mathcal{Z}(\mathbf{p}, L - t_0|u) = \Delta(p^+, L - t_0) \int \frac{d\mathbf{p}'}{(2\pi)^2} \mathcal{P}(\mathbf{p}' - \mathbf{p}, L - t_0)\, u(\mathbf{p}')$$

$$+\alpha_s \int_{t_0}^{L} dt\, \Delta(p^+, t - t_0) \int_0^1 \frac{dz}{z} \int \frac{d\mathbf{p}'}{(2\pi)^2} \mathcal{P}(\mathbf{p}' - \mathbf{p}, L - t_0) \int \frac{d\boldsymbol{q}}{(2\pi)^2} \mathcal{K}(\boldsymbol{q} - z\mathbf{p}'|z)\, \mathcal{Z}(\mathbf{q}, L - t|u)\, \mathcal{Z}(\mathbf{p}' - \mathbf{q}, L - t|u)$$

Master Equation



$$\mathcal{Z}(\mathbf{p}, L-t_0|u) = \Delta(p^+, L-t_0) \int \frac{d\boldsymbol{p}'}{(2\pi)^2} \mathcal{P}(\boldsymbol{p}'-\boldsymbol{p}, L-t_0)\, u(\mathbf{p}')$$
$$+\alpha_s \int_{t_0}^{L} dt\, \Delta(p^+, t-t_0) \int_0^1 \frac{dz}{z} \int \frac{d\boldsymbol{p}'}{(2\pi)^2} \mathcal{P}(\boldsymbol{p}'-\boldsymbol{p}, L-t_0) \int \frac{d\boldsymbol{q}}{(2\pi)^2} \mathcal{K}(\boldsymbol{q}-z\boldsymbol{p}'|z)\, \mathcal{Z}(\mathbf{q}, L-t|u)\, \mathcal{Z}(\mathbf{p}'-\mathbf{q}, L-t|u)$$

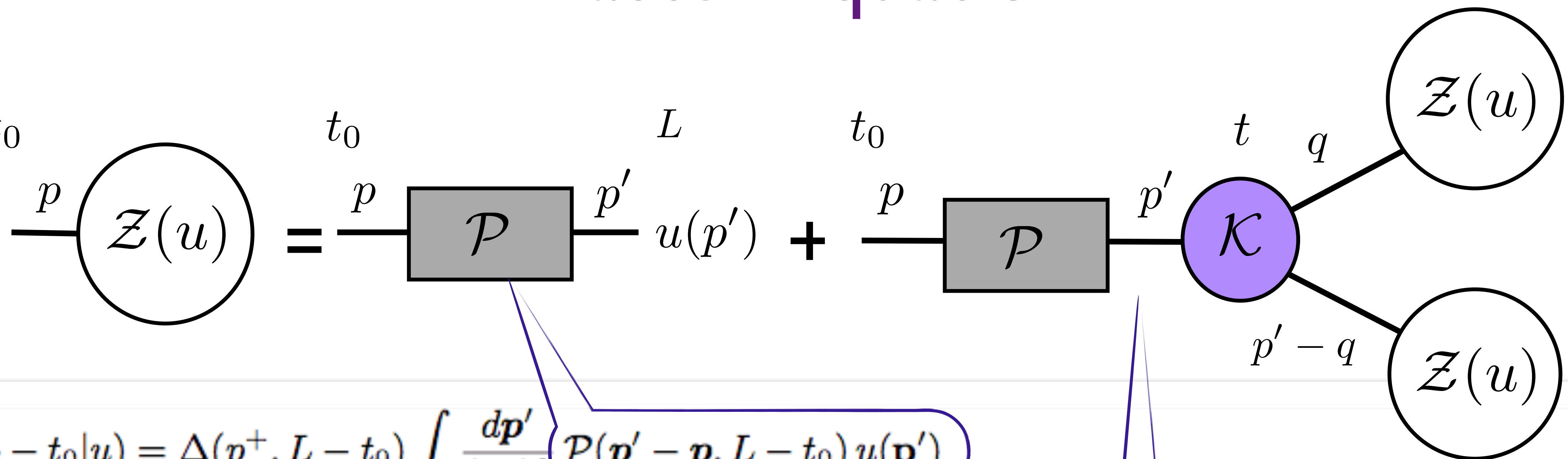
- In-medium splitting function

$$\mathcal{K}_{BC}^{A}(\boldsymbol{q}-z\boldsymbol{p},\, z) = \frac{2}{p^+} P_{AB}(z)\ \sin\left[\frac{(\boldsymbol{q}-z\boldsymbol{p})^2}{2\boldsymbol{k}_{\rm br}^2}\right] \exp\left[-\frac{(\boldsymbol{q}-z\boldsymbol{p})^2}{2\boldsymbol{k}_{\rm br}^2}\right]$$

- Relative pT at branching time

$$\boldsymbol{k}_{\rm br}^2 = \sqrt{z(1-z)p^+\hat{q}_{\rm eff}}$$

Master Equation



$$\mathcal{Z}(\mathbf{p}, L-t_0|u) = \Delta(p^+, L-t_0)\int \frac{d\boldsymbol{p}'}{(2\pi)^2}\mathcal{P}(\boldsymbol{p}'-\boldsymbol{p}, L-t_0)\,u(\mathbf{p}')$$
$$+\alpha_s\int_{t_0}^{L} dt\,\Delta(p^+, t-t_0)\int_0^1\frac{dz}{z}\int\frac{d\boldsymbol{p}'}{(2\pi)^2}\mathcal{P}(\boldsymbol{p}'-\boldsymbol{p}, L-t_0)\int\frac{d\boldsymbol{q}}{(2\pi)^2}\mathcal{K}(\boldsymbol{q}-z\boldsymbol{p}'|z)\,\mathcal{Z}(\mathbf{q}, L-t|u)\,\mathcal{Z}(\mathbf{p}'-\mathbf{q}, L-t|u)$$

- In-medium splitting function

$$\mathcal{K}_{BC}^{A}(\boldsymbol{q}-z\boldsymbol{p},\, z) = \frac{2}{p^+}P_{AB}(z)\,\sin\left[\frac{(\boldsymbol{q}-z\boldsymbol{p})^2}{2\boldsymbol{k}_{\mathrm{br}}^2}\right]\exp\left[-\frac{(\boldsymbol{q}-z\boldsymbol{p})^2}{2\boldsymbol{k}_{\mathrm{br}}^2}\right]$$

- Relative pT at branching time

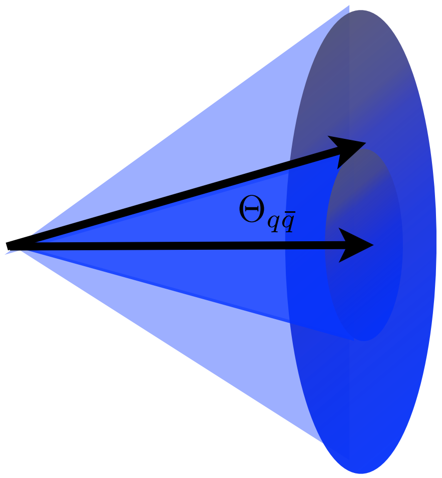
$$\boldsymbol{k}_{\mathrm{br}}^2 = \sqrt{z(1-z)p^+\hat{q}_{\mathrm{eff}}}$$

- Sudakov form factor:

Prob. not to emit (Unitarity)

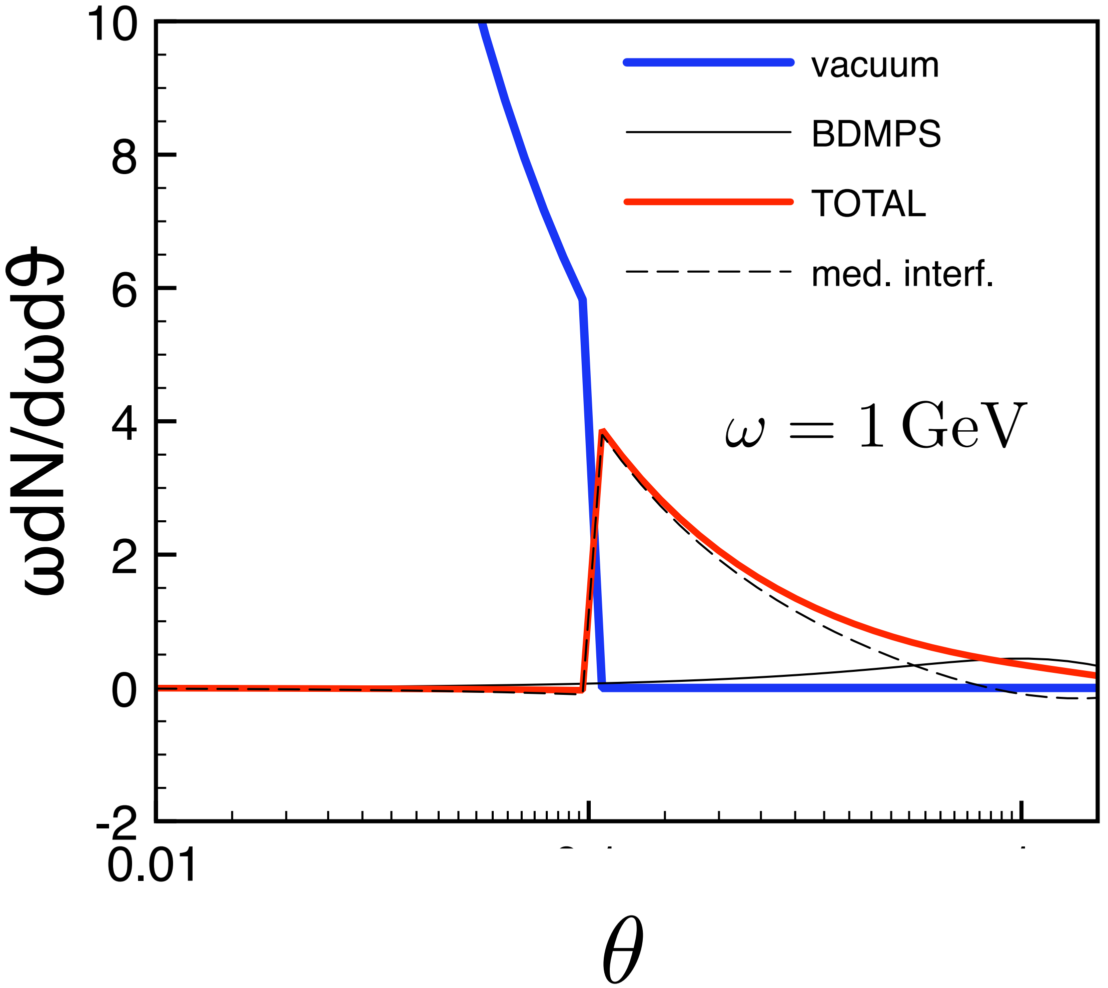
$$\Delta(p^+, L-t_0) = \exp\left[-\alpha_s(L-t_0)\int_0^1\frac{dz}{z}\mathcal{K}(z)\right]$$

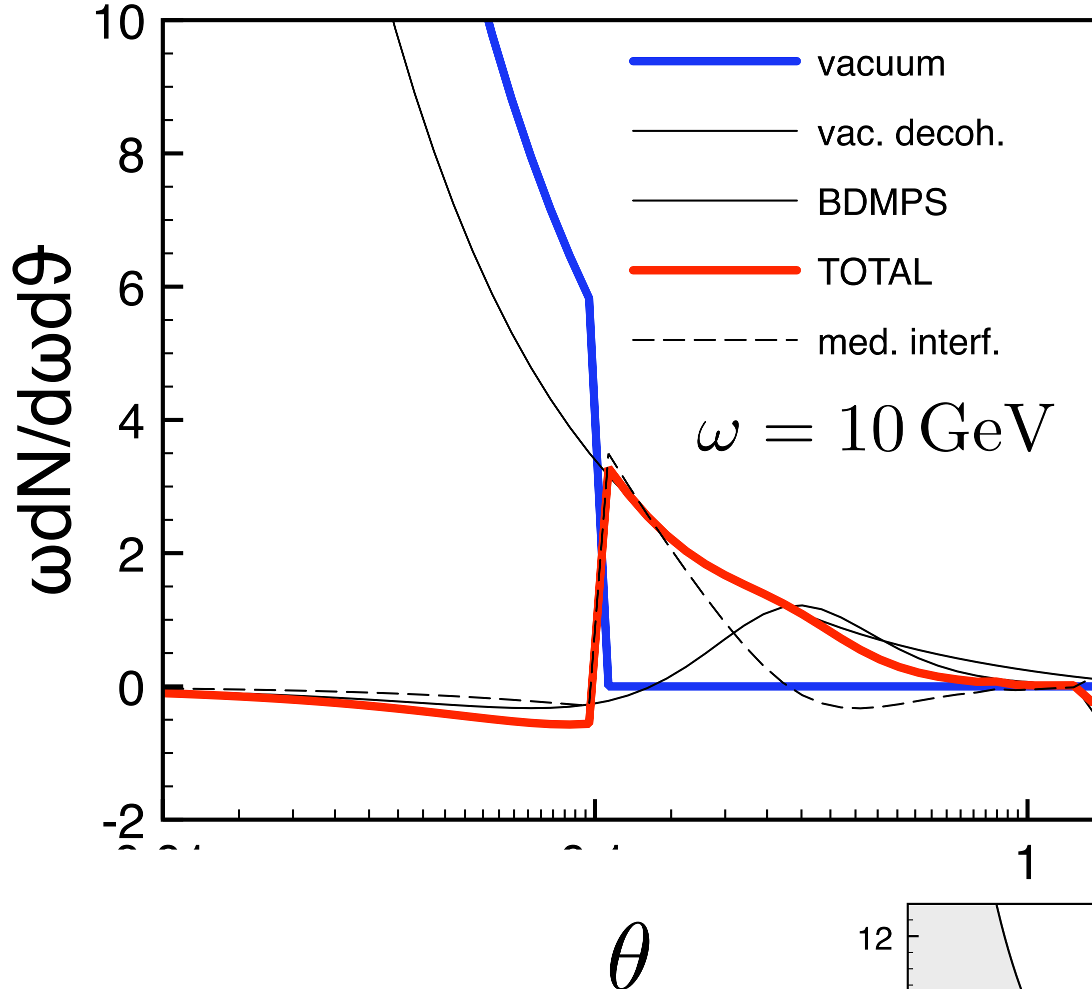
Angular distribution ($r_\perp < Q_s^{-1}$)



- Dipole regime

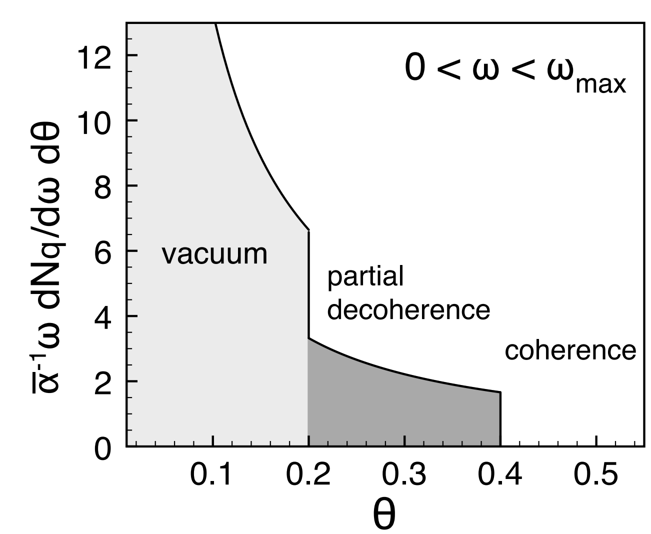
$\hat{q} = 1\,\mathrm{GeV}^2/\mathrm{fm} \qquad \theta_{q\bar{q}} = 0.1 \qquad L = 5\,\mathrm{fm}$





$$dN_q^{\mathrm{ind}} \propto \mathcal{R}_q^{\mathrm{ind}} - \mathcal{J}^{\mathrm{ind}}$$

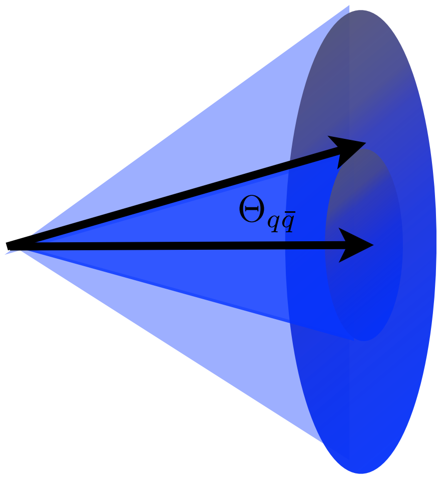
integrating over the azimuth

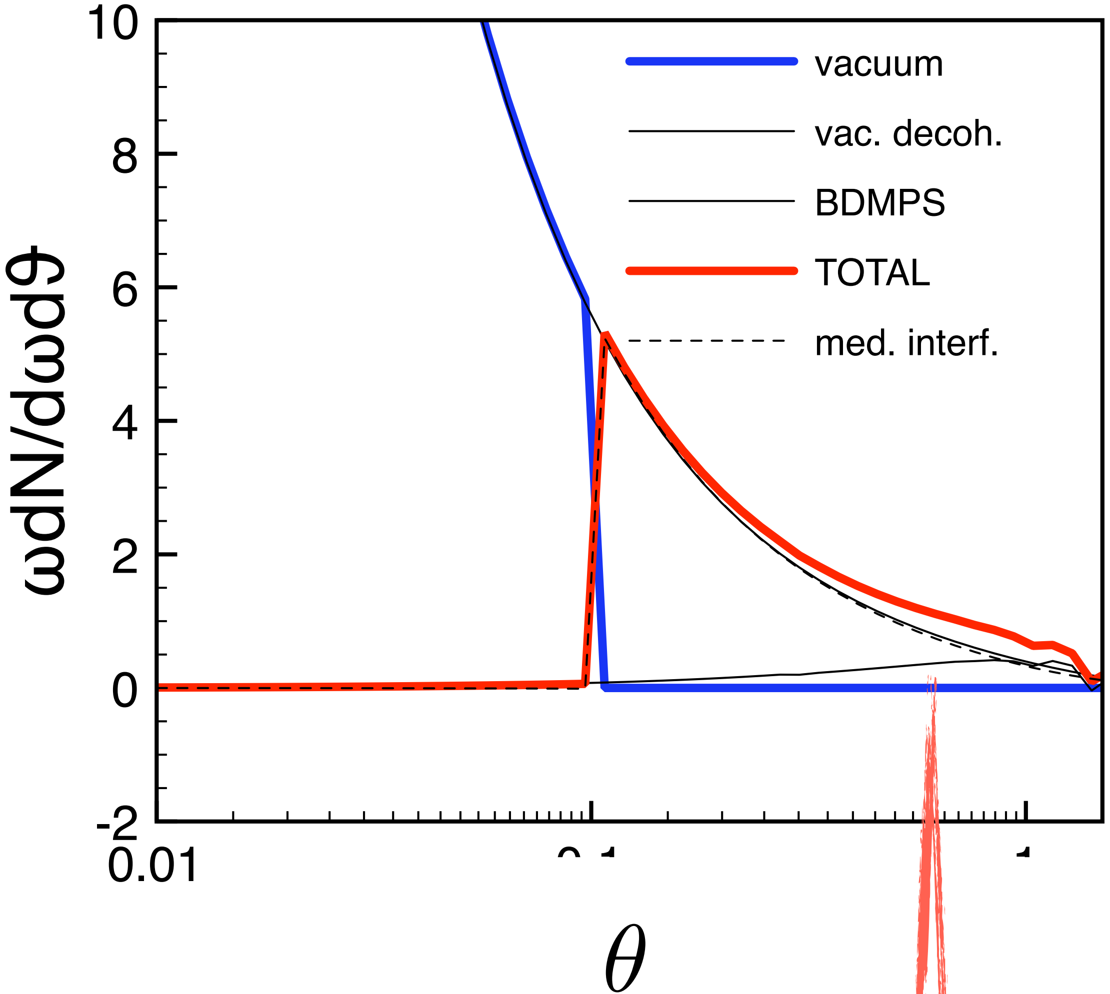


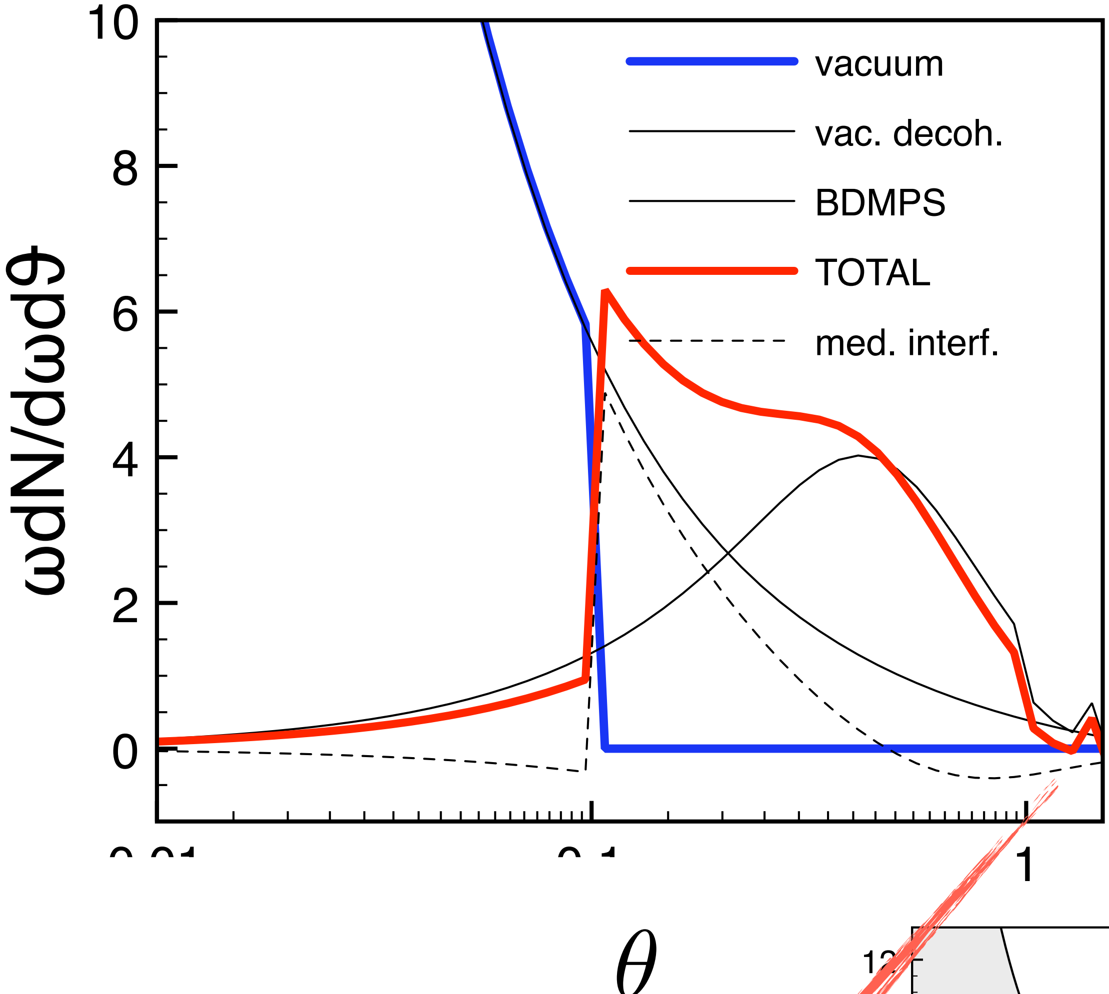
Angular distribution ($r_\perp > Q_s^{-1}$)

- Decoherence regime

$\hat{q} = 5\,\mathrm{GeV}^2/\mathrm{fm}$ $\theta_{q\bar{q}} = 0.1$ $L = 10\,\mathrm{fm}$

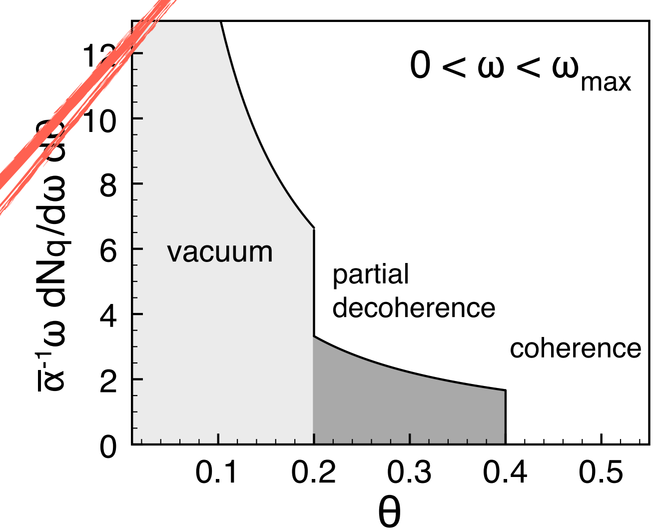






Decoherence

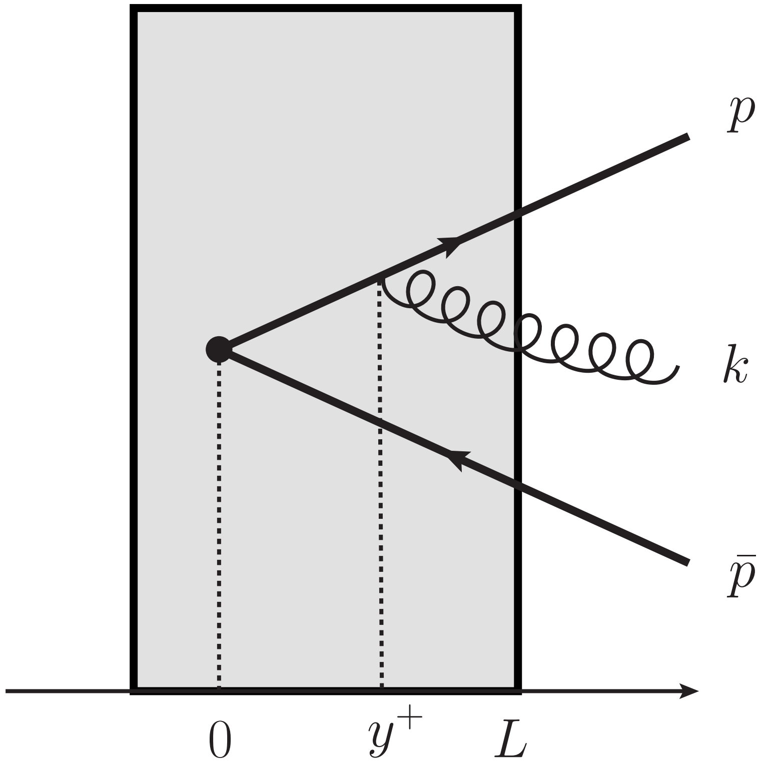
Coherence: $k_\perp > Q_s$



Classical Yang Mills

Gluon propagator (Brownian motion in the transverse plan)

$$\mathcal{G}\left(x^+,\boldsymbol{x};y^+,\boldsymbol{y}|k^+\right) = \int \mathcal{D}[\boldsymbol{r}]\,\exp\left[i\frac{k^+}{2}\int_{y^+}^{x^+} d\xi\,\dot{\boldsymbol{r}}^2(\xi)\right] U(x^+,y^+;[\boldsymbol{r}])$$



The amplitude for gluon radiation off the quark

$$\mathcal{M}^a_{\lambda,q}(\vec{k}) = \frac{g}{k^+}\int\limits_{x^+=+\infty} d^2\boldsymbol{x}\,e^{ik^-x^+-i\boldsymbol{k}\cdot\boldsymbol{x}}\int_0^{+\infty} dy^+ e^{i\frac{k^+p^-}{p^+}y^+}$$

$$\times\,\boldsymbol{\epsilon}_\lambda\cdot\left(i\boldsymbol{\partial}_y + k^+\boldsymbol{n}\right)\mathcal{G}^{ab}(x^+,\boldsymbol{x}\,;\,y^+,\boldsymbol{y}\,|k^+)\Big|_{\boldsymbol{y}=\boldsymbol{n}\,y^+} U^{bc}_p(y^+,0)Q^c_q\,,$$

$$\boldsymbol{n} = \boldsymbol{p}/p^+$$

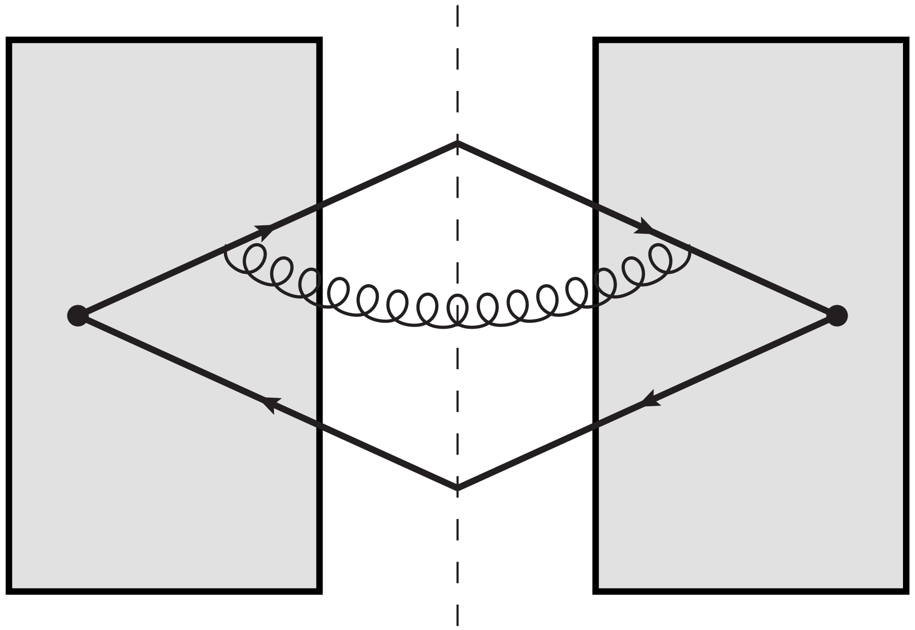
Classical Yang Mills

Independent emission off the quark (BDMPS-Z spectrum)

$$\mathcal{R}_q = 2\,\mathrm{Re}\left\{\int_0^\infty dy'^+ \int_0^{y'^+} dy^+ \int d^2\boldsymbol{z}\, \exp\left[-i\boldsymbol{\kappa}\cdot\boldsymbol{z} - \frac{1}{2}\int_{y'^+}^\infty d\xi\, n(\xi)\sigma(\boldsymbol{z})\right] \right.$$
$$\left. \times\, \boldsymbol{\partial}_y \cdot \boldsymbol{\partial}_z \mathcal{K}(y'^+, \boldsymbol{z}\,;\, y^+, \boldsymbol{y} = \boldsymbol{0}\,|k^+)\right\},$$

$$\boldsymbol{\kappa} = \boldsymbol{k} - x\boldsymbol{p}$$

$$x = k^+/p^+$$



Classical Yang Mills

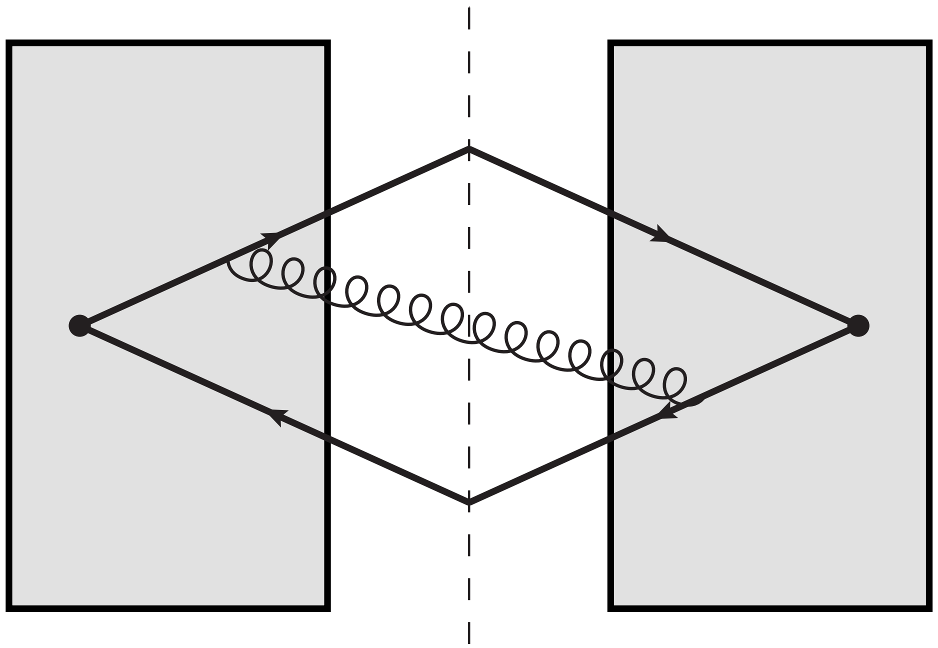
Interferences

Y. M.-T. and K. Tywoniuk 1105.1346 [hep-ph]
J. Casalderrey-Solana and E. Iancu arXiv:1105.1760 (JHEP 2011)

$$\mathcal{J} = \mathrm{Re}\left\{\int_0^\infty dy'^+ \int_0^{y'^+} dy^+ \left(1-\Delta_{\mathrm{med}}(y^+,0)\right)\right.$$
$$\times \int d^2\boldsymbol{z}\, \exp\left[-i\bar{\boldsymbol{\kappa}}\cdot\boldsymbol{z} - \frac{1}{2}\int_{y'^+}^\infty d\xi\, n(\xi)\sigma(\boldsymbol{z}) + i\frac{k^+}{2}\delta\boldsymbol{n}^2 y^+\right]$$
$$\left.\times \left(\boldsymbol{\partial}_y - ik^+\,\delta\boldsymbol{n}\right)\cdot\boldsymbol{\partial}_z\, \mathcal{K}(y'^+,\boldsymbol{z}\,;\,y^+,\boldsymbol{y}\,|k^+)\Big|_{\boldsymbol{y}=\delta\boldsymbol{n}y^+}\right\} + \mathrm{sym.}$$

$$\boldsymbol{\kappa} = \boldsymbol{k} - x\boldsymbol{p} \qquad x = k^+/p^+$$

$$|\delta\boldsymbol{n}| \equiv \sin\theta_{q\bar{q}} \sim \theta_{q\bar{q}}$$



Decoherence parameter

$$\frac{1}{N_c^2-1}\langle \mathbf{Tr}\, U_p(y^+,0)U_{\bar{p}}^\dagger(y^+,0)\rangle = 1 - \Delta_{\mathrm{med}}(y^+,0)$$