INTERFERENCE BETWEEN INITIAL AND FINAL STATE IN A QCD MEDIUM

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Hot Quarks 2012
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N. Armesto, H. Ma, Y. Mehtar-Tani and C. Salgado
Phys. Lett. B 717 (2012) 280-286

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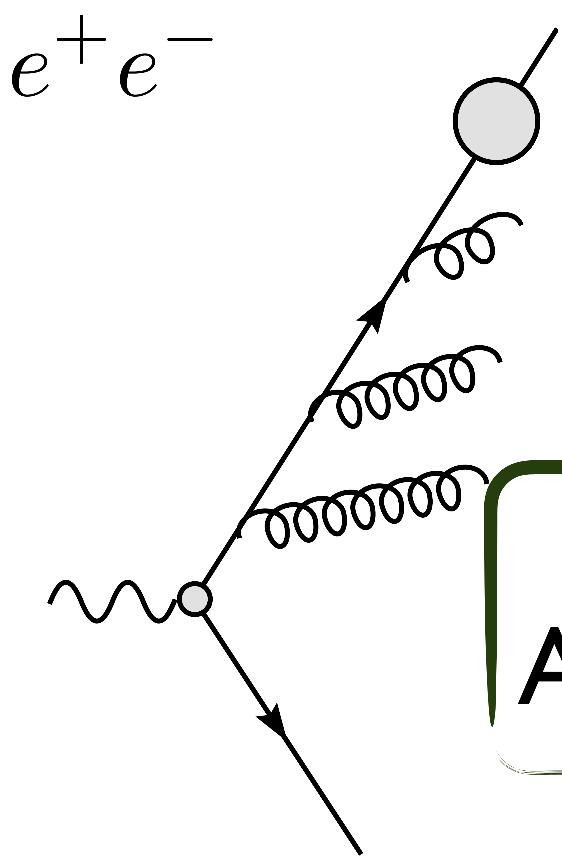
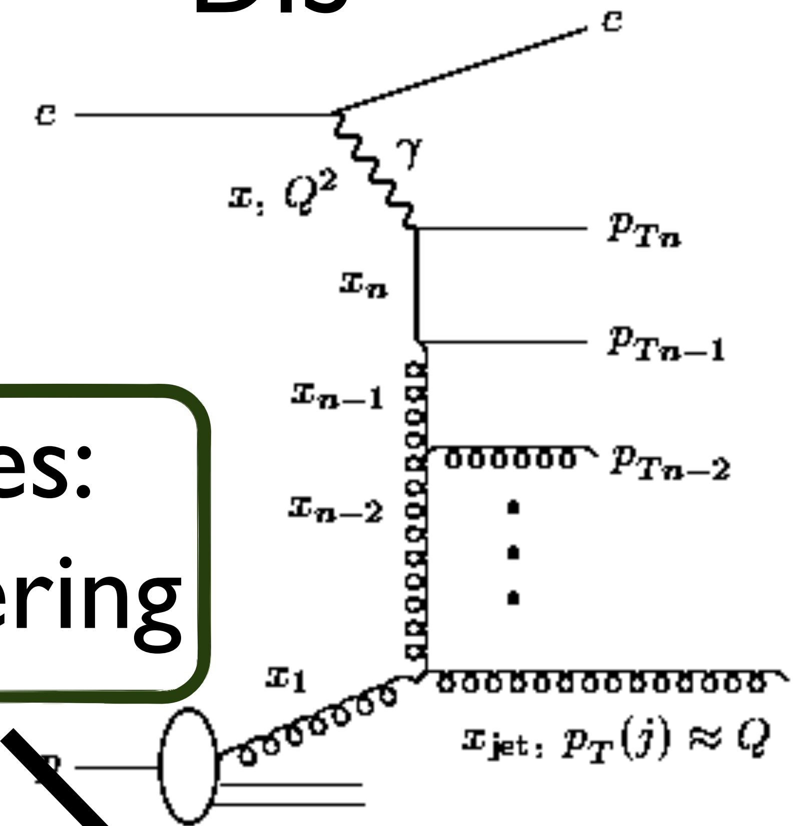
Parton cascades



DIS



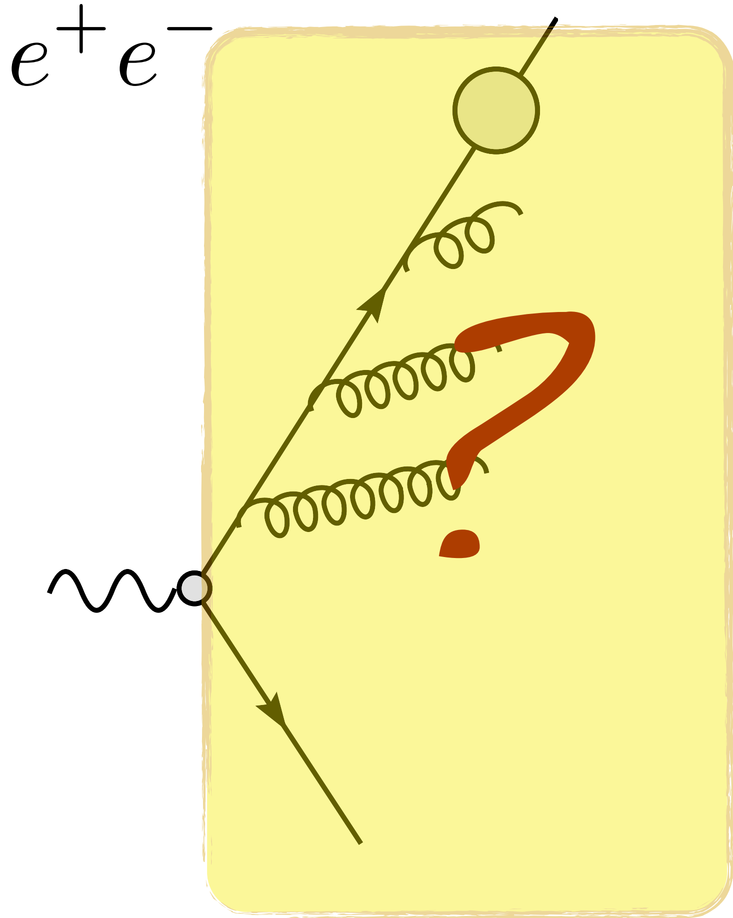
Interferences:
Angular Ordering

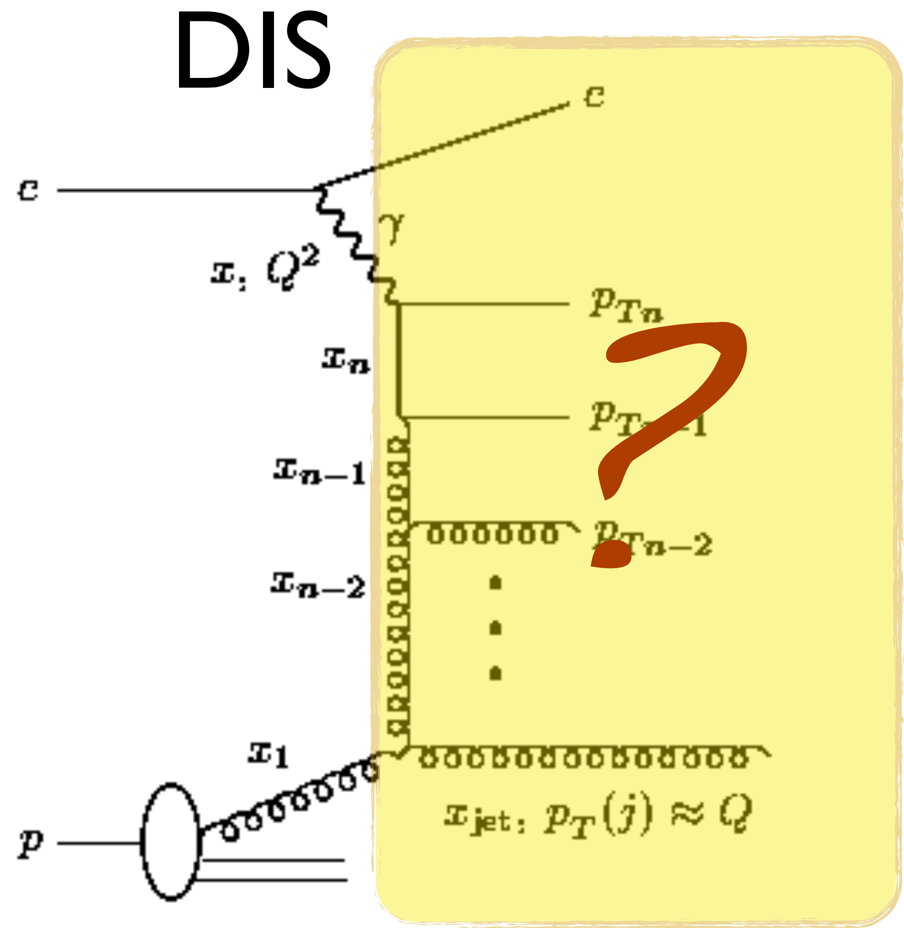
Time-like
Fragmentation functions

Space-like
PDF's

Jets in HIC

Is coherence pattern altered by a QCD medium?





Medium induced gluon radiation formalism assumes independent emissions so no interferences between different emitters

First steps: $q\bar{q}$ antenna in a QCD medium

Dilute medium

- Massless antenna:

Y. Mehtar-Tani, C. Salgado and K. Tywoniuk, PRL 106 (2011) 122002, JHEP 1204 (2012) 064.

- Massive antenna:

A. Armesto, H. Ma, Y. Mehtar-Tani, C. Salgado and K. Tywoniuk, JHEP 1201(2012) 109.

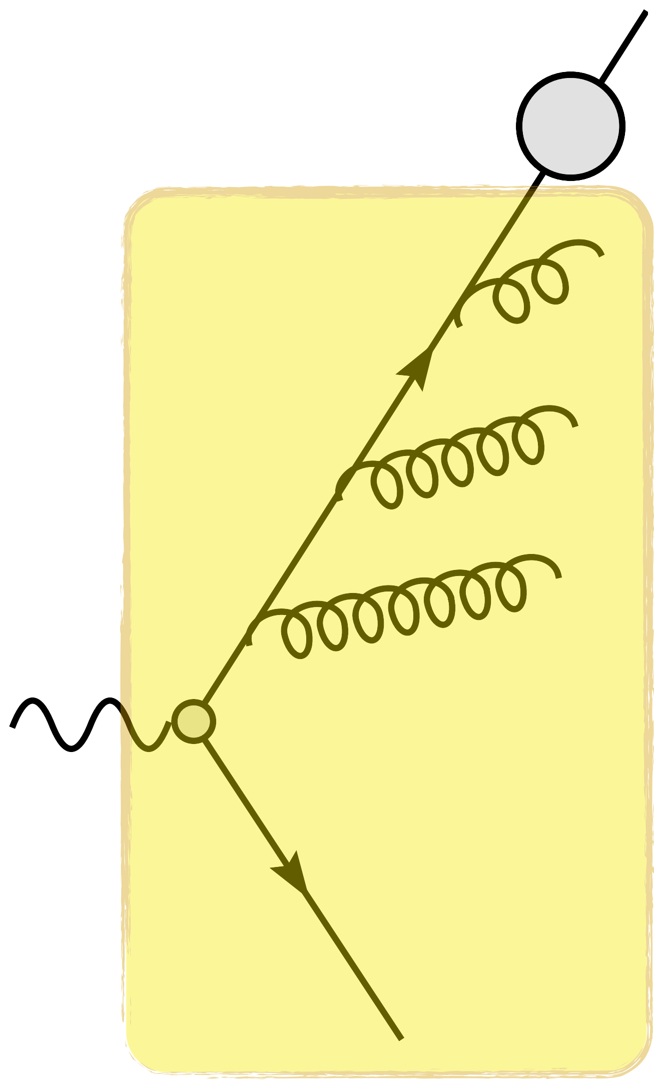
Opaque dense medium

- Massless antenna:

Y. Mehtar-Tani, C. Salgado and K. Tywoniuk, PLB 707 (2012), 156.

Y. Mehtar-Tani and K. Tywoniuk, arXiV:1105.1346.

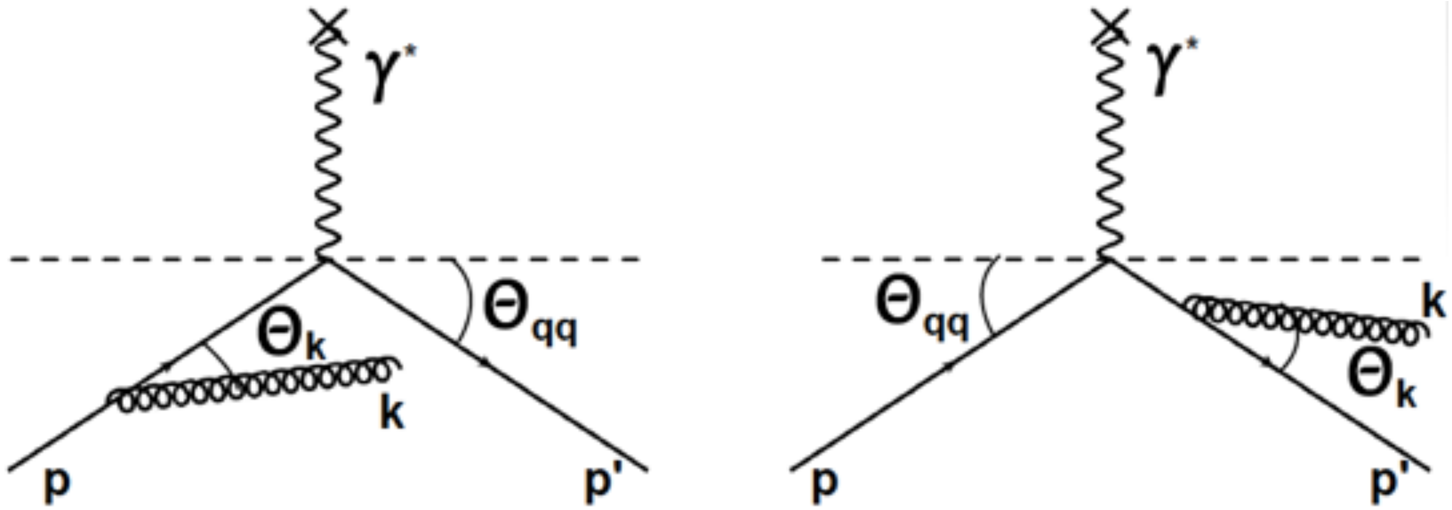
J. Casalderrey and E. Iancu, JHEP 1108 (2011) 015.



Medium induced gluon branching:

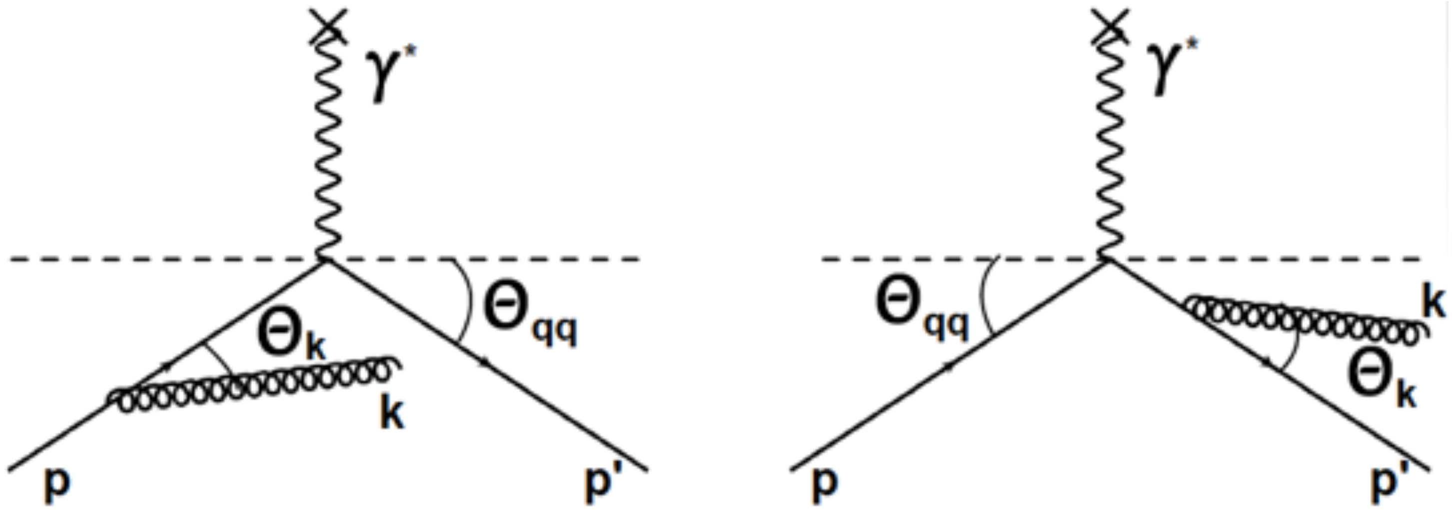
Blaizot et. al, arXiV: 1209.4585

Interference pattern between initial and final state radiation: Vacuum case



$$\omega \frac{dN^{\mathrm{vac}}}{d^3\vec{k}} = \frac{\alpha_s C_F}{(2\pi)^2\,\omega^2}\left(\mathcal{P}_{in}^{vac} + \mathcal{P}_{out}^{vac}\right)$$

Interference pattern between initial and final state radiation: Vacuum case



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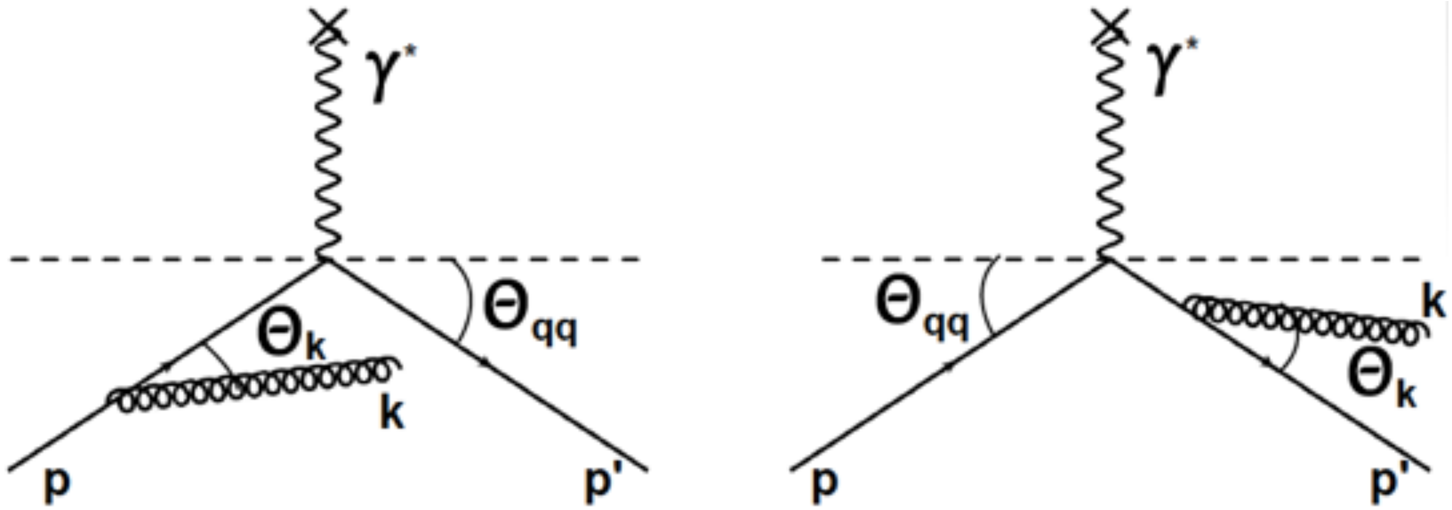
Color charge

Interference pattern between initial and final state radiation: Vacuum case



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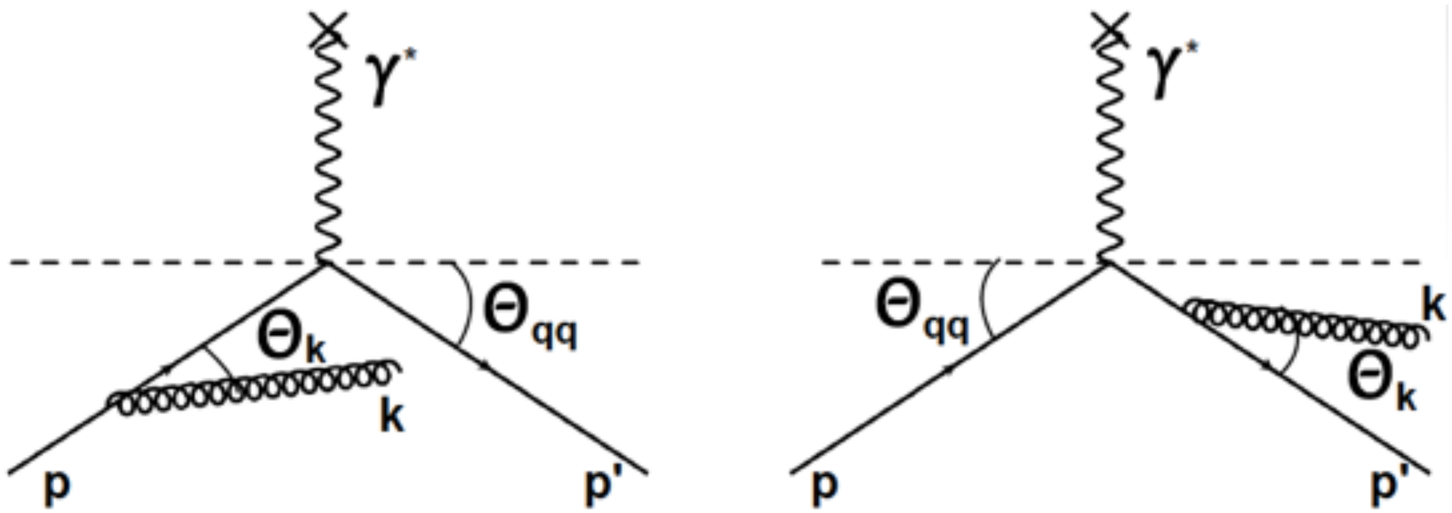
Color charge

Independent emissions

Interference pattern between initial and final state radiation: Vacuum case

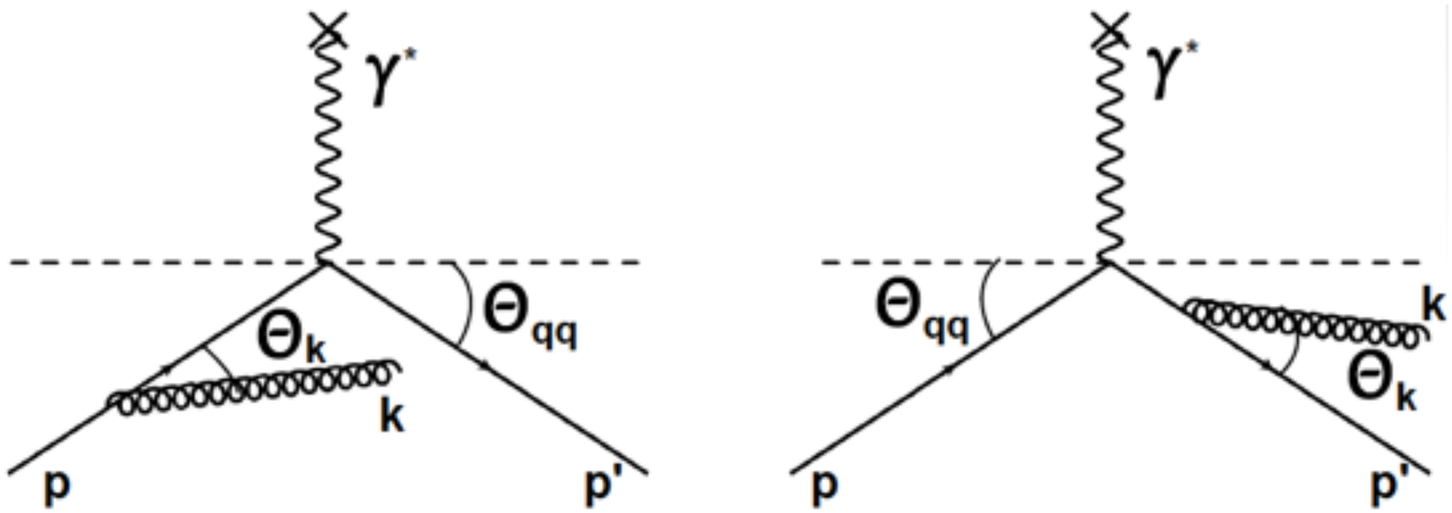


$$\omega \frac{dN^{\text{vac}}}{d^3\vec{k}} = \frac{\alpha_s\, C_F}{(2\pi)^2\, \omega^2} \left(\mathcal{P}^{vac}_{in} + \mathcal{P}^{vac}_{out}\right)$$

$$\mathcal{P}^{vac}_{in} = \mathcal{R}_{in} - \mathcal{J} \qquad \kappa = k_\perp - xP_\perp$$

Incoherent emission: $4\omega^2 \frac{1}{\kappa^2}$

Interference pattern between initial and final state radiation: Vacuum case



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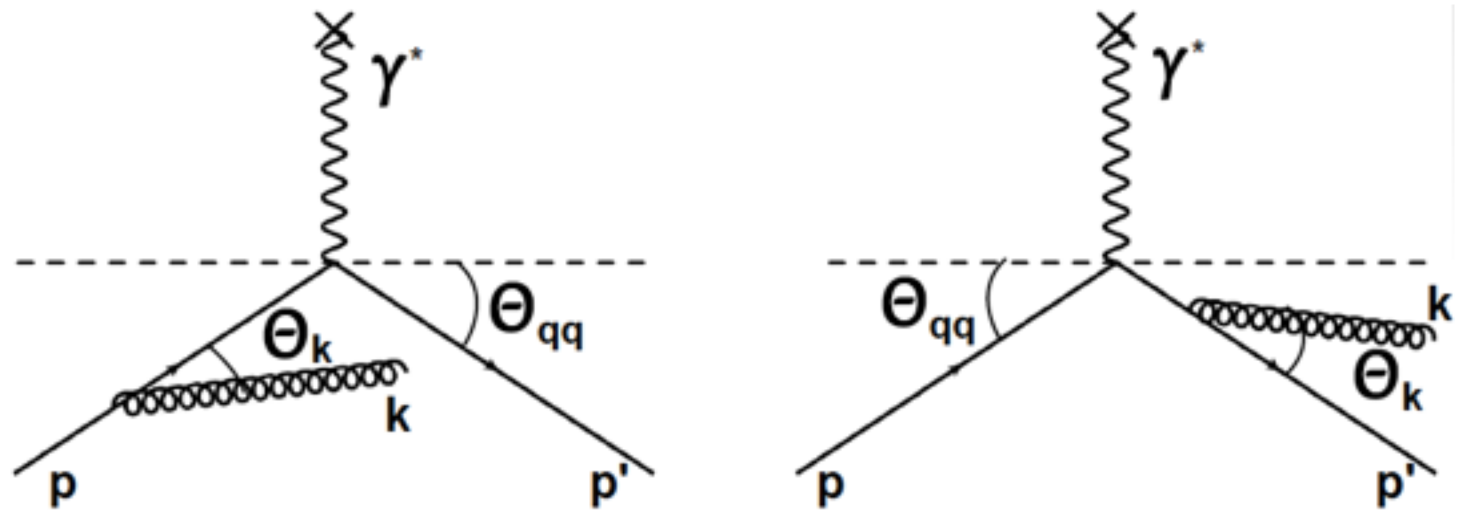
$$\mathcal{P}_{in}^{vac} = \mathcal{R}_{in} - \mathcal{J} \qquad \kappa = k_\perp - x P_\perp$$

Incoherent emission: $4\omega^2 \frac{1}{\kappa^2}$

Interference: $4\omega^2 \frac{\kappa \cdot \bar{\kappa}}{\kappa^2 \bar{\kappa}^2}$

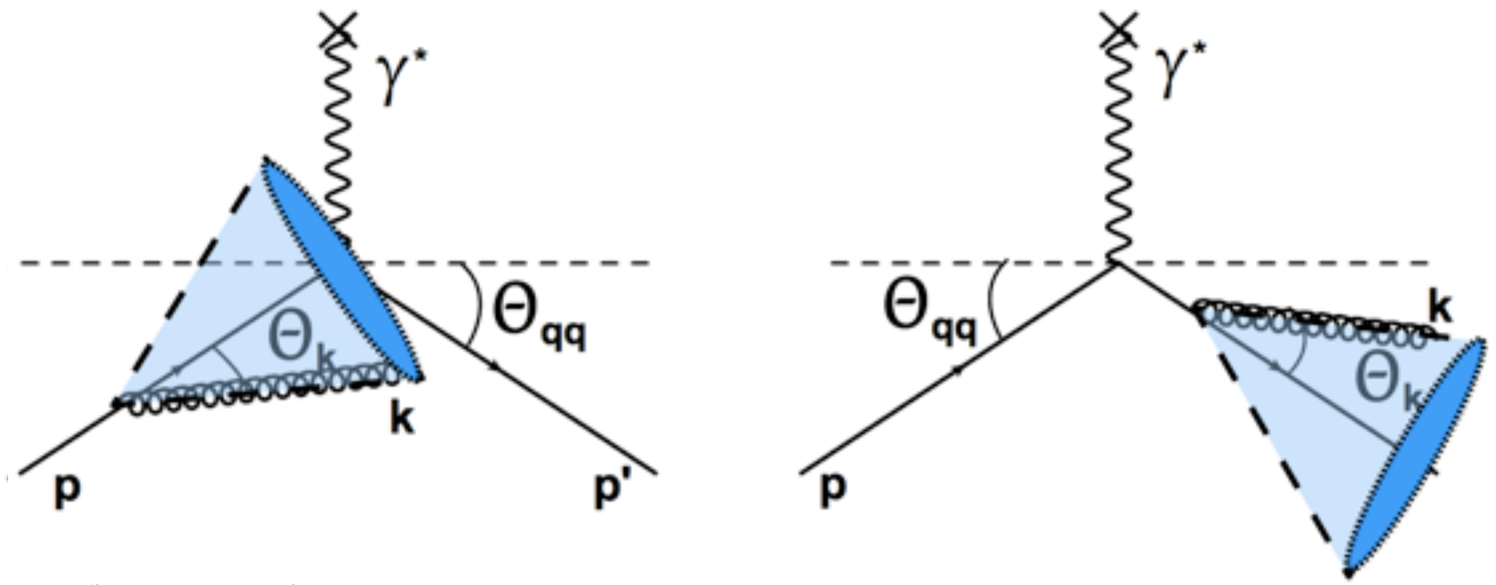
Interference pattern between initial and final state radiation: Vacuum case



$$\langle dN_{in}\rangle \propto \frac{d\omega}{\omega}\frac{d\theta_{in}}{\theta_{in}}\Theta\left(\theta_{p\bar{p}}-\theta_{in}\right)$$

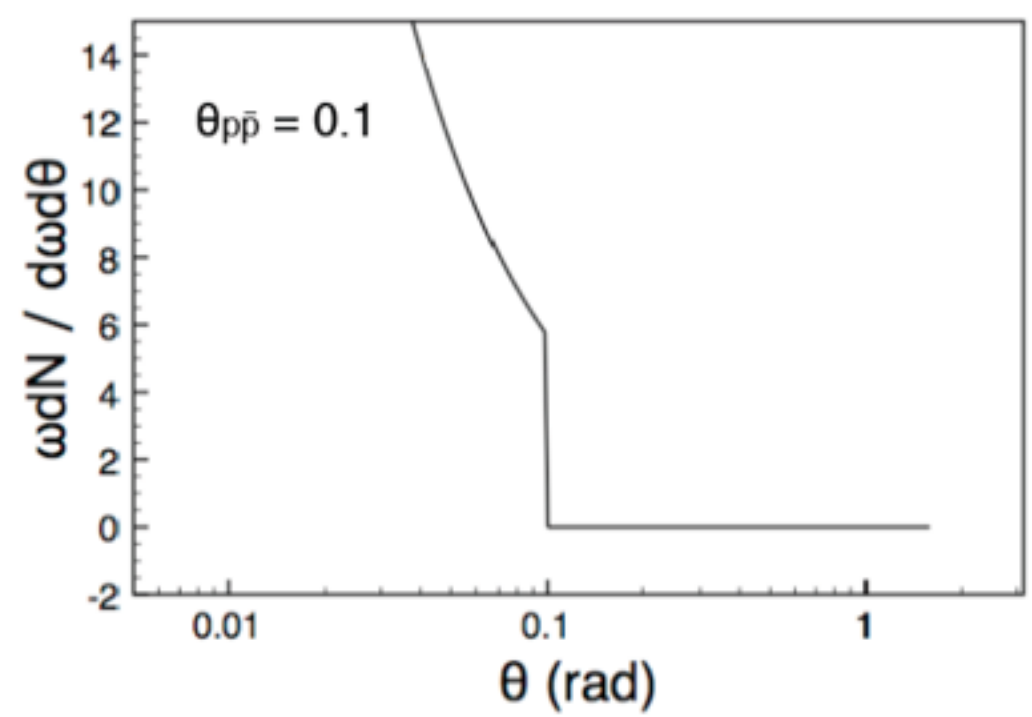
- Infrared and collinear divergences

Interference pattern between initial and final state radiation: Vacuum case

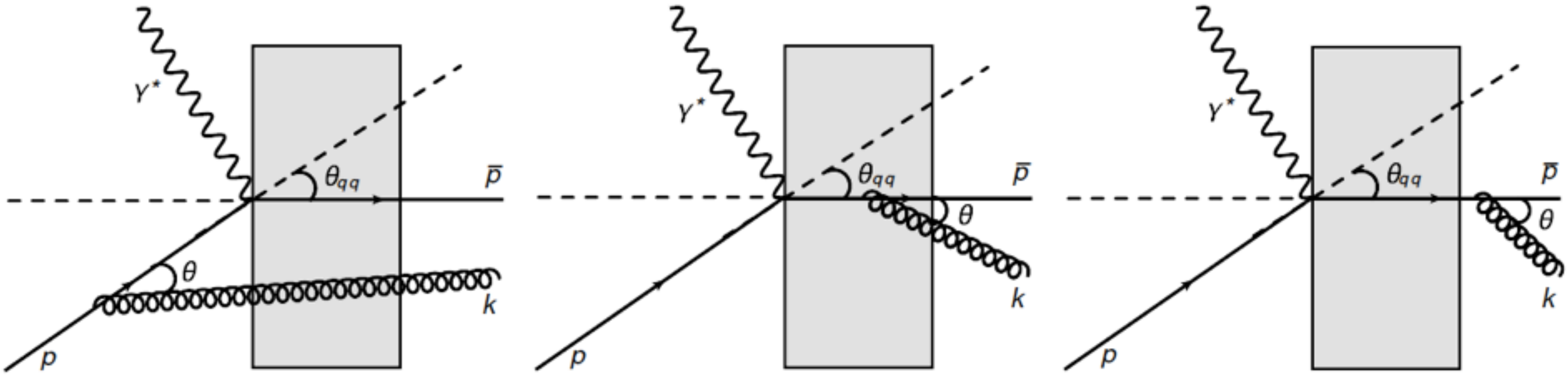


$$\langle dN_{in} \rangle \propto \frac{d\omega}{\omega}\frac{d\theta_{in}}{\theta_{in}}\Theta\left(\theta_{p\bar{p}} - \theta_{in}\right)$$

- Infrared and collinear divergences
- Coherence: reduction of soft gluon emissions at large angles due to destructive interferences.



Medium modifications to the initial and final state interference pattern

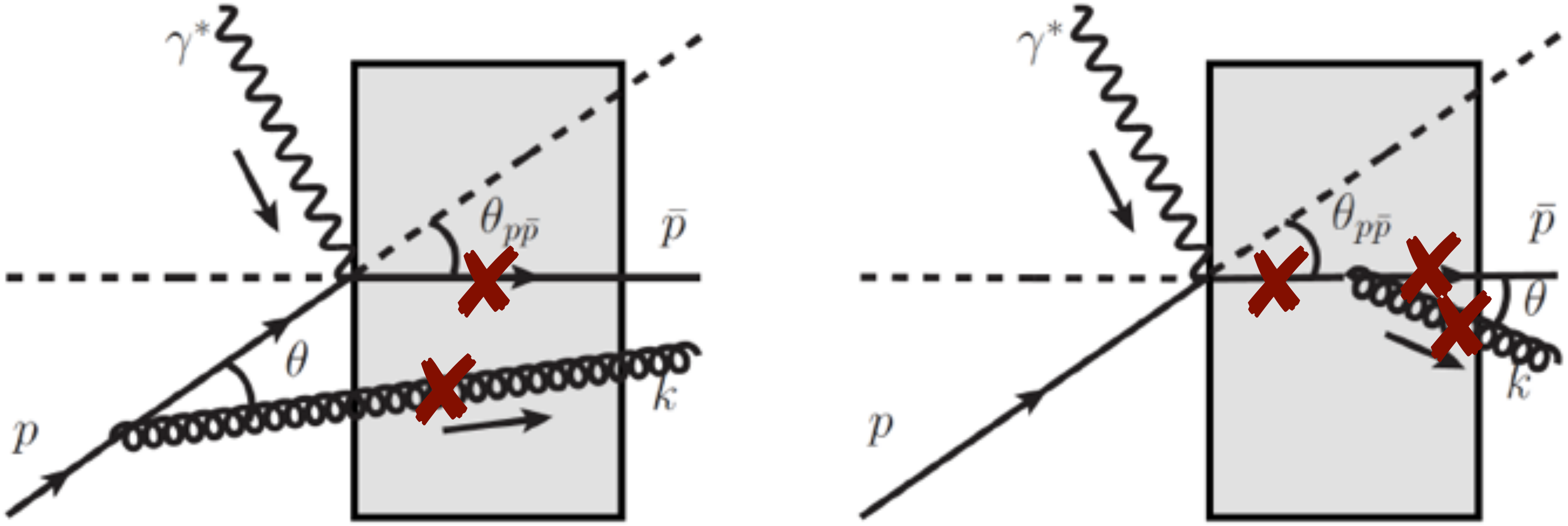


GOALS

☆ Study another configuration relevant to HI collisions

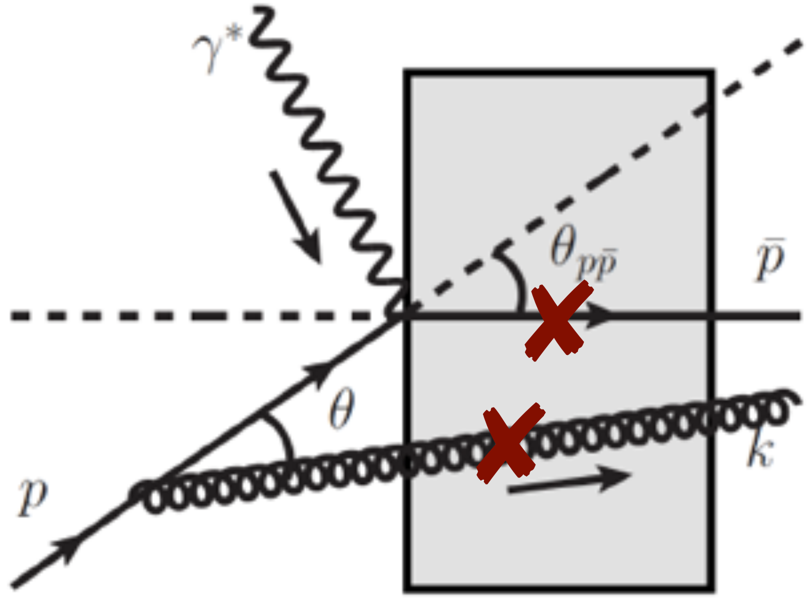
☆ Investigate medium modifications to the Initial State Radiation

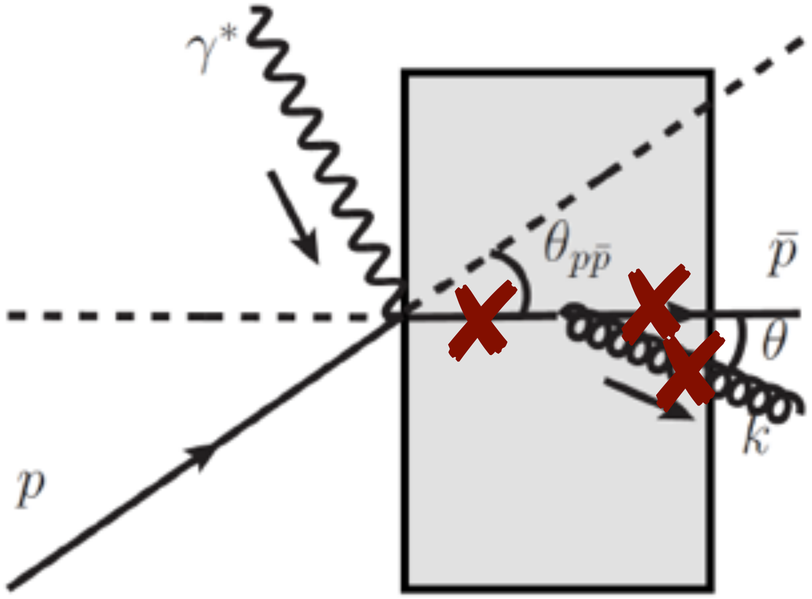
Setup



γ^*
$\theta_{p\bar{p}}$
$\bar{p}$
θ
p
k
γ^*
$\theta_{p\bar{p}}$
$\bar{p}$
θ
p
k

Setup

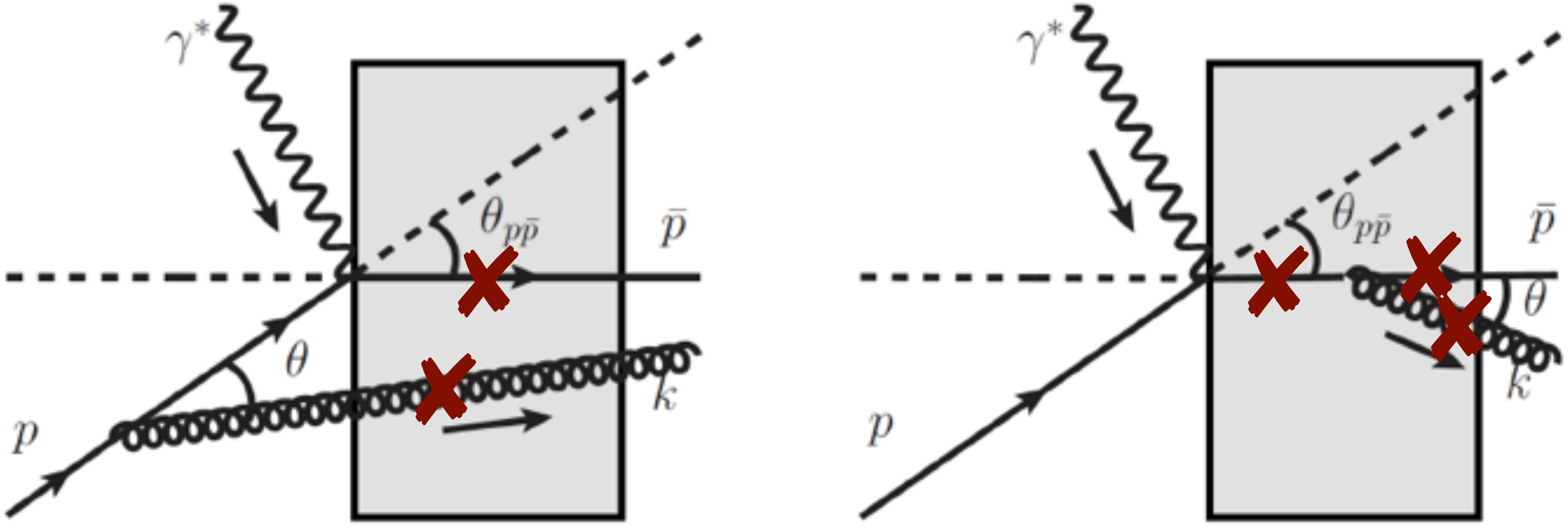




- Expansion in terms of the density of scattering centers:

$$\bar{n} \approx \frac{L}{\lambda} \ll 1$$

Setup



- Expansion in terms of the density of scattering centers:

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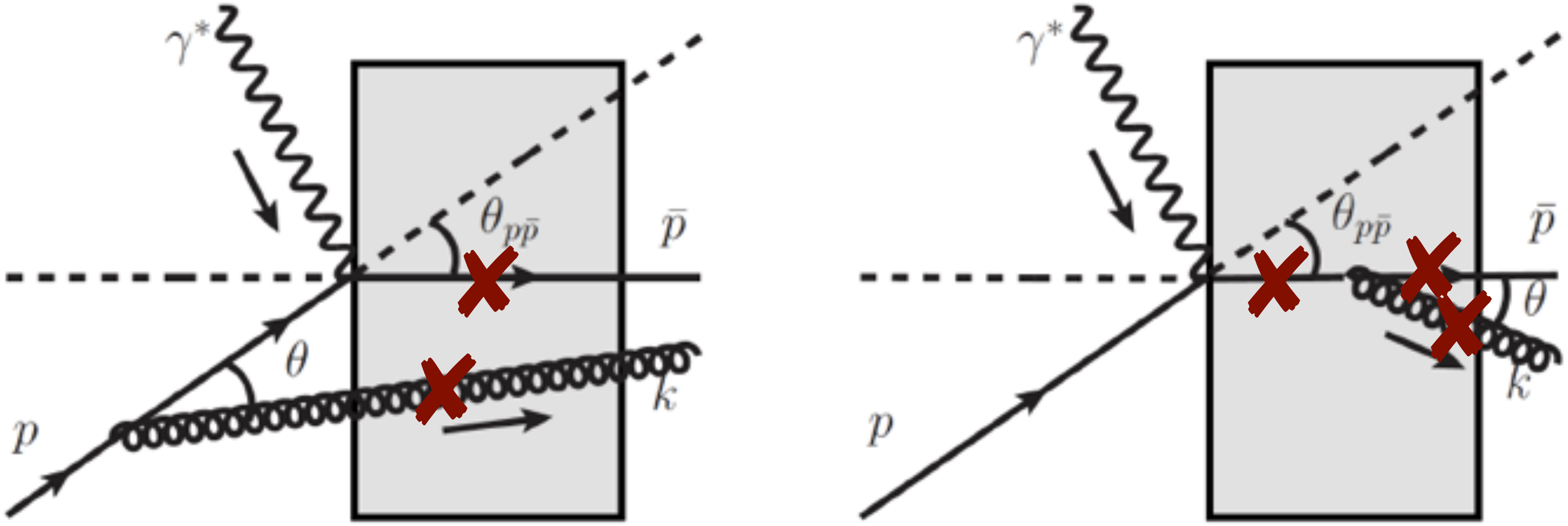
- No longitudinal correlations between scattering centers.

Setup



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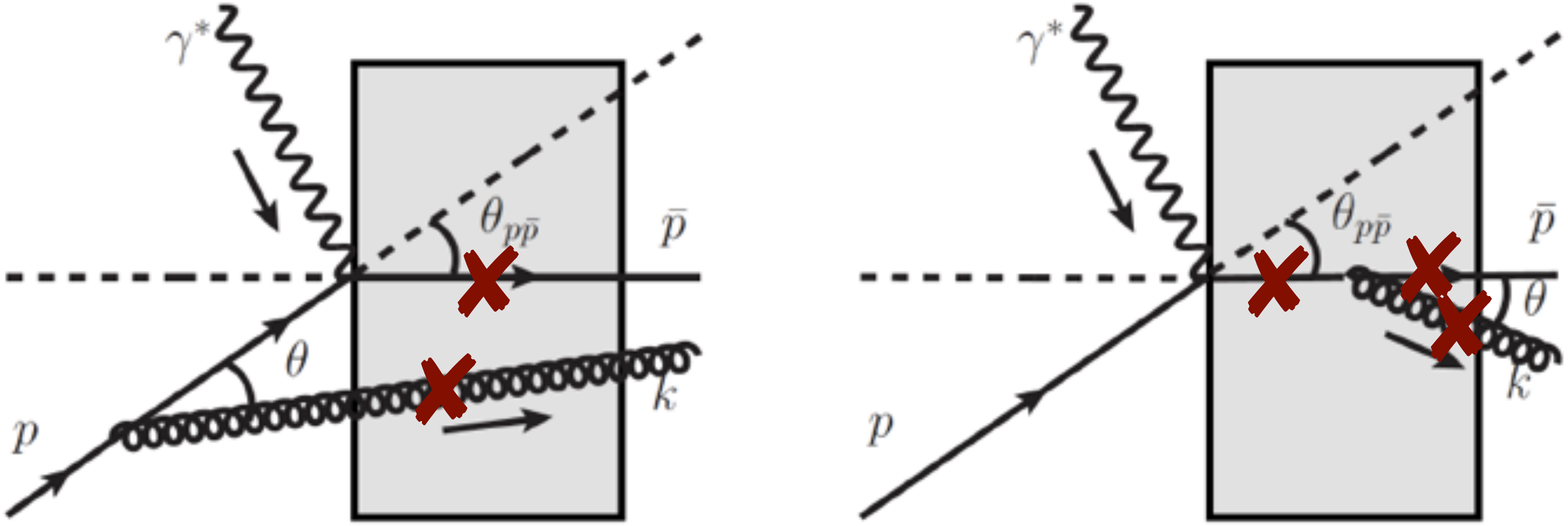
- Eikonal approximation: $E >> \omega >> k_\perp, q_\perp$

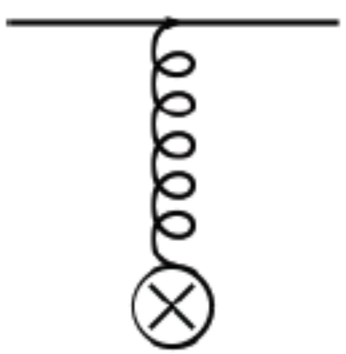
Setup



- Expansion in terms of the density of scattering centers:

$$\bar{n} \approx \frac{L}{\lambda} \ll 1$$

- No longitudinal correlations between scattering centers.
- Eikonal approximation: $E >> \omega >> k_\perp, q_\perp$
- The scattering centers are static (Gaussian random noise):



$$U_0(\boldsymbol{x}) = \frac{Ze^2}{4\pi} \frac{e^{-M|\boldsymbol{x}|}}{|\boldsymbol{x}|}$$

Gyulassy-Wang
NPB 420 (1994) 583

N= 1 scattering amplitude

$$\mathcal{M}^a_\lambda = 2ig^2 \int \frac{d^2\mathbf{q}}{(2\pi)^2} \int_0^{L^+} dx^+ [T \cdot A^-_{med}(x^+, \mathbf{q})]$$

$$\times \left\{ Q^b_{in} \frac{\kappa - \mathbf{q}}{(\kappa - \mathbf{q})^2} - Q^b_{out} \left[\frac{\bar{\kappa} - \mathbf{q}}{(\bar{\kappa} - \mathbf{q})^2} \right] - \bar{\mathbf{L}} \exp\left(i \frac{(\bar{\kappa} - \mathbf{q})^2}{2k^+} x^+ \right) \right\}$$

N= 1 scattering amplitude

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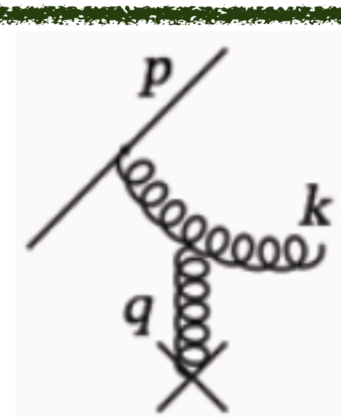
Emission with rescattering before the QCD medium



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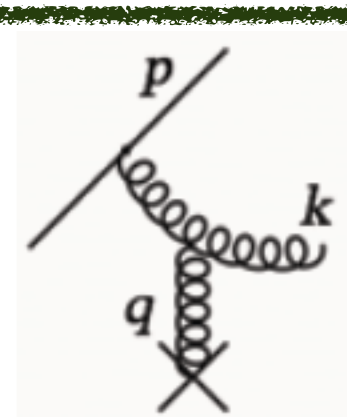
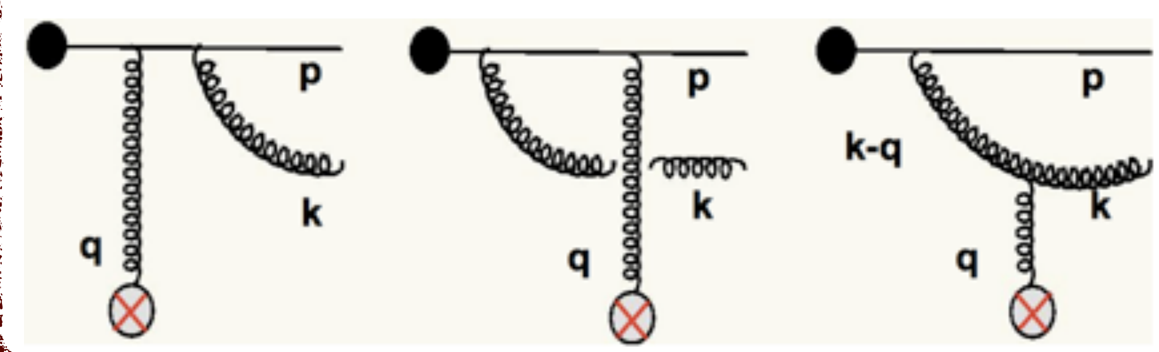
Emission with rescattering before the QCD medium

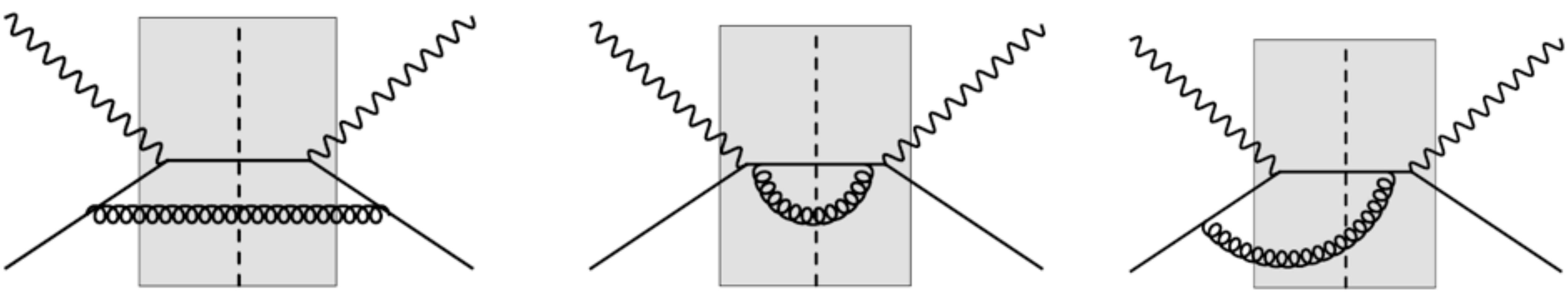


GLV: Medium induced emission off an off-shell particle



The medium induced gluon spectrum

$$
\omega \frac{dN^{\rm med}}{d^3\vec{k}} = \frac{4\,\alpha_s C_F\,\hat{q}}{\pi} \int \frac{d^2\boldsymbol{q}}{(2\pi)^2}\mathcal{V}^2(\boldsymbol{q}) \int_0^{L^+} dx^+ \left[\frac{1}{(\boldsymbol{\kappa}-\boldsymbol{q})^2} - \frac{1}{\boldsymbol{\kappa}^2} \right.
$$
$$
+\ 2\,\frac{\bar{\boldsymbol{\kappa}}\cdot\boldsymbol{q}}{\bar{\boldsymbol{\kappa}}^2(\bar{\boldsymbol{\kappa}}-\mathbf{q})^2}\left(1-\cos\left[\frac{(\boldsymbol{k}_\perp-\boldsymbol{q})^2}{2k^+}x^+\right]\right)
$$
$$
\left. -\ 2\left\{\boldsymbol{L}\cdot\frac{\bar{\boldsymbol{\kappa}}}{\bar{\boldsymbol{\kappa}}^2} + \bar{\boldsymbol{L}}\cdot\frac{(\boldsymbol{\kappa}-\boldsymbol{q})}{(\boldsymbol{\kappa}-\boldsymbol{q})^2}\left(1-\cos\left[\frac{(\boldsymbol{k}-\boldsymbol{q})^2}{2k^+}x^+\right]\right)\right\}\right]
$$



Ini. *Med.* *Int.*

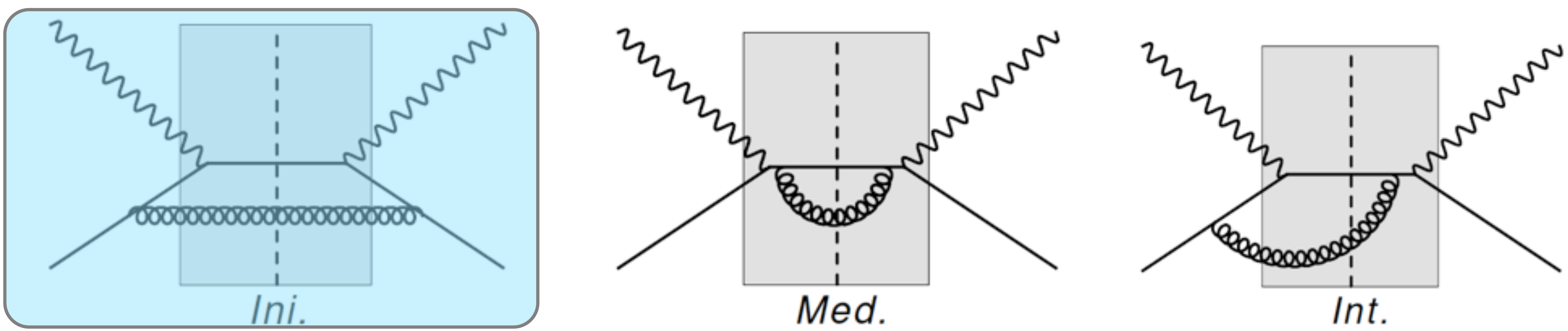
The medium induced gluon spectrum

Reshuffling of the on shell incoming parton

$$\omega \frac{dN^{\rm med}}{d^3\vec{k}} = \frac{4\,\alpha_s C_F\,\hat{q}}{\pi} \int \frac{d^2\boldsymbol{q}}{(2\pi)^2} \mathcal{V}^2(\boldsymbol{q}) \int_0^{L^+} dx^+ \left[\frac{1}{(\boldsymbol{\kappa}-\boldsymbol{q})^2} - \frac{1}{\boldsymbol{\kappa}^2} \right.$$

$$+\, 2\, \frac{\bar{\boldsymbol{\kappa}}\cdot\boldsymbol{q}}{\bar{\boldsymbol{\kappa}}^2(\bar{\boldsymbol{\kappa}}-\mathbf{q})^2} \left(1-\cos\left[\frac{(\boldsymbol{k}_\perp-\boldsymbol{q})^2}{2k^+}x^+\right]\right)$$

$$\left. -\, 2 \left\{ \boldsymbol{L}\cdot\frac{\bar{\boldsymbol{\kappa}}}{\bar{\boldsymbol{\kappa}}^2} + \bar{\boldsymbol{L}}\cdot\frac{(\boldsymbol{\kappa}-\boldsymbol{q})}{(\boldsymbol{\kappa}-\boldsymbol{q})^2} \left(1-\cos\left[\frac{(\boldsymbol{k}-\boldsymbol{q})^2}{2k^+}x^+\right]\right) \right\} \right]$$



The medium induced gluon spectrum

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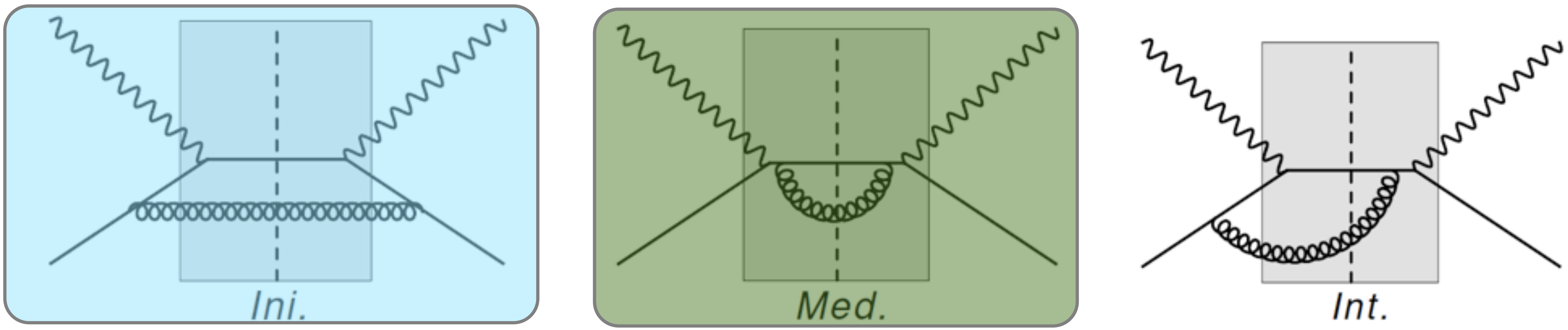
$$+ 2 \frac{\bar{\boldsymbol{\kappa}} \cdot \boldsymbol{q}}{\bar{\boldsymbol{\kappa}}^2 (\bar{\boldsymbol{\kappa}} - \mathbf{q})^2} \left(1 - \cos\left[\frac{(\boldsymbol{k}_\perp - \boldsymbol{q})^2}{2k^+} x^+\right]\right) \qquad \text{GLV}$$

$$- 2 \left\{ \boldsymbol{L} \cdot \frac{\bar{\boldsymbol{\kappa}}}{\bar{\boldsymbol{\kappa}}^2} + \bar{\boldsymbol{L}} \cdot \frac{(\boldsymbol{\kappa} - \boldsymbol{q})}{(\boldsymbol{\kappa} - \boldsymbol{q})^2} \left(1 - \cos\left[\frac{(\boldsymbol{k} - \boldsymbol{q})^2}{2k^+} x^+\right]\right) \right\} \Bigg]$$



The medium induced gluon spectrum

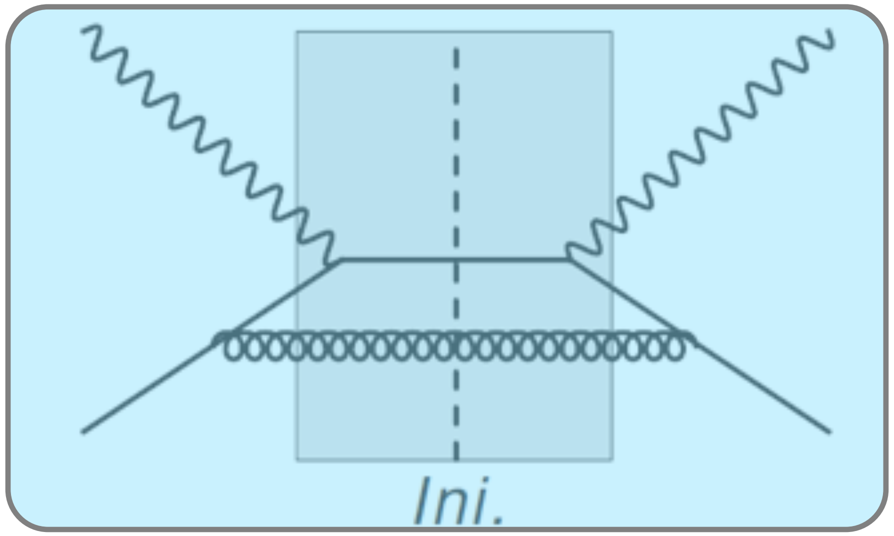
Reshuffling of the on shell incoming parton

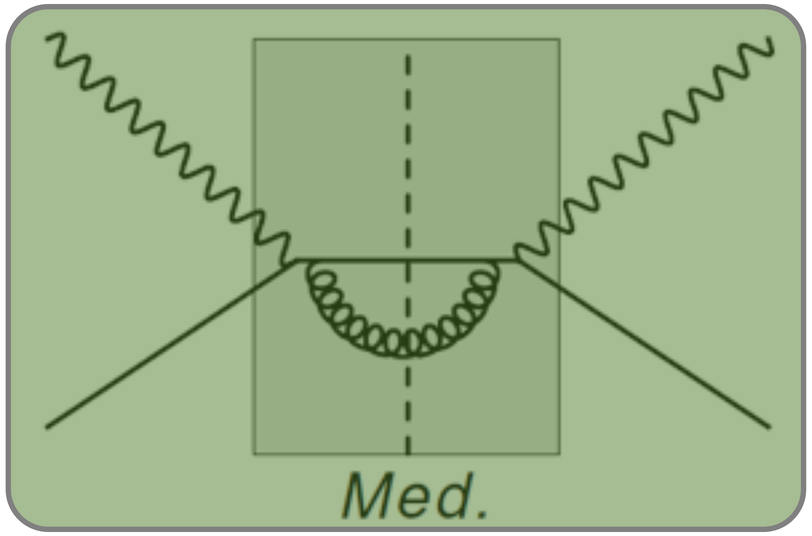
$$\omega \frac{dN^{\text{med}}}{d^3\vec{k}} = \frac{4\,\alpha_s C_F\,\hat{q}}{\pi} \int \frac{d^2\boldsymbol{q}}{(2\pi)^2} \mathcal{V}^2(\boldsymbol{q}) \int_0^{L^+} dx^+ \Bigg[\frac{1}{(\boldsymbol{\kappa}-\boldsymbol{q})^2} - \frac{1}{\boldsymbol{\kappa}^2}$$

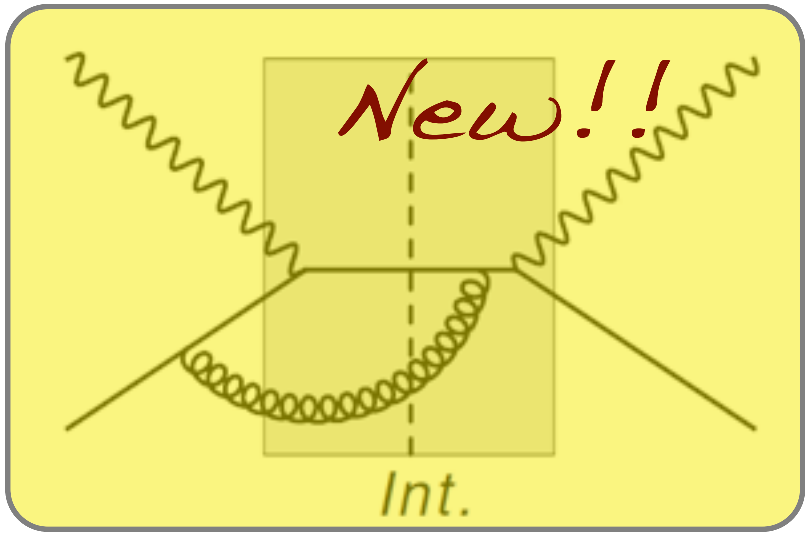
$$+ 2\, \frac{\bar{\boldsymbol{\kappa}}\cdot\boldsymbol{q}}{\bar{\boldsymbol{\kappa}}^2(\bar{\boldsymbol{\kappa}}-\mathbf{q})^2}\left(1-\cos\left[\frac{(\boldsymbol{k}_\perp-\boldsymbol{q})^2}{2k^+}x^+\right]\right) \quad \text{GLV}$$

Interferences

$$- 2\left\{ \boldsymbol{L}\cdot\frac{\bar{\boldsymbol{\kappa}}}{\bar{\boldsymbol{\kappa}}^2} + \bar{\boldsymbol{L}}\cdot\frac{(\boldsymbol{\kappa}-\boldsymbol{q})}{(\boldsymbol{\kappa}-\boldsymbol{q})^2}\left(1-\cos\left[\frac{(\boldsymbol{k}-\boldsymbol{q})^2}{2k^+}x^+\right]\right)\right\}\Bigg]$$







The medium induced gluon spectrum: Incoherent limit

$$\omega \left.\frac{dN^{med}}{d^3\vec{k}}\right|_{\tau_f<L} = \frac{4\alpha_s C_F \hat{q}}{\pi}\int \frac{d^2\mathbf{q}}{(2\pi)^2}\mathcal{V}(\mathbf{q})\int_0^{L^+} dx^+\{\bar{\mathbf{L}}^2 + \mathcal{C}^2(\kappa - q) - \mathcal{C}^2(\kappa)\}$$

$$\bar{L} = \left(\frac{\bar{\kappa} - q}{(\bar{\kappa} - q)^2} - \frac{\bar{\kappa}}{\bar{\kappa}^2}\right)^2$$

$$\mathcal{C}(\kappa) = \left(\frac{\kappa}{\kappa^2} - \frac{\bar{\kappa}}{\bar{\kappa}^2}\right)^2$$

$$\mathcal{C}(\kappa - q) = \left(\frac{\kappa - q}{(\kappa - q)^2} - \frac{\bar{\kappa} - q}{(\bar{\kappa} - q)^2}\right)^2$$

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$$\bar{L} = \left(\frac{\bar{\kappa} - q}{(\bar{\kappa} - q)^2} - \frac{\bar{\kappa}}{\bar{\kappa}^2}\right)^2$$

Medium induced radiation of an asymptotic parton due to the scattering with the medium

$$\mathcal{C}(\kappa) = \left(\frac{\kappa}{\kappa^2} - \frac{\bar{\kappa}}{\bar{\kappa}^2}\right)^2$$

$$\mathcal{C}(\kappa - q) = \left(\frac{\kappa - q}{(\kappa - q)^2} - \frac{\bar{\kappa} - q}{(\bar{\kappa} - q)^2}\right)^2$$

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$$\bar{L} = \left(\frac{\bar{\kappa} - q}{(\bar{\kappa} - q)^2} - \frac{\bar{\kappa}}{\bar{\kappa}^2}\right)^2$$

→ Medium induced radiation of an asymptotic parton due to the scattering with the medium

$$\mathcal{C}(\kappa) = \left(\frac{\kappa}{\kappa^2} - \frac{\bar{\kappa}}{\bar{\kappa}^2}\right)^2$$

→ Bremmstrahlung associated to the hard scattering

$$\mathcal{C}(\kappa - q) = \left(\frac{\kappa - q}{(\kappa - q)^2} - \frac{\bar{\kappa} - q}{(\bar{\kappa} - q)^2}\right)^2$$

→ same + rescatt.

The medium induced gluon spectrum: Coherent limit

$$\omega \frac{dN^{med}}{d^3\vec{k}}\bigg|_{\tau_f \gg L^+} = \frac{4\alpha_s C_F \hat{q}}{\pi} \int \frac{d^2\mathbf{q}}{(2\pi)^2} \mathcal{V}^2(\mathbf{q}) \int_0^{L^+} dx^+ \left\{ \frac{1}{(\kappa - \mathbf{q})^2} - \frac{1}{\kappa^2} + 2\frac{\bar{\kappa}\cdot\kappa}{\bar{\kappa}^2\kappa^2} - 2\frac{\bar{\kappa}\cdot(\kappa - q)}{\bar{\kappa}^2(\kappa - q)^2} \right\}$$

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- Reshuffling of the gluon emission off the incoming quark

The medium induced gluon spectrum: Coherent limit

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- Reshuffling of the gluon emission off the incoming quark

- Interferences (No phase !!!):
  - ◆ GLV contribution is supressed due to LPM.
  - ◆ Gluon emission of the outcoming quark does not rescatter inside the medium and is produced outside of it.

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The full gluon spectrum: Soft limit and probabilistic interpretation

$$\omega \frac{dN^{\rm tot}}{d^3\vec{k}}\bigg|_{\omega\to 0} = \omega \frac{dN^{\rm vac}}{d^3\vec{k}}\bigg|_{\omega\to 0} + \omega \frac{dN^{\rm med}}{d^3\vec{k}}\bigg|_{\omega\to 0}$$

$$= \frac{\alpha_s\, C_F}{(2\pi)^2}\left(\mathcal{P}_{in} + \mathcal{P}_{out}\right)$$

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The full gluon spectrum: Soft limit and probabilistic interpretation

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$$\Delta_{med} = \frac{\hat{q}L^+}{m_D^2}$$ Opacity parameter

$$\mathcal{P}_{in} = \left(1 - \Delta_{med}\right)\left(\mathcal{R}_{in} - \mathcal{J}\right)$$

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$$\mathcal{P}_{out} = \left(\mathcal{R}_{out} - \mathcal{J}\right) + \Delta_{med}\mathcal{J}$$

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$$\mathcal{P}_{out} = \left(\mathcal{R}_{out} - \mathcal{J}\right) + \Delta_{med}\mathcal{J}$$ → Partial decoherence of the final state

The full gluon spectrum: Soft limit and probabilistic interpretation

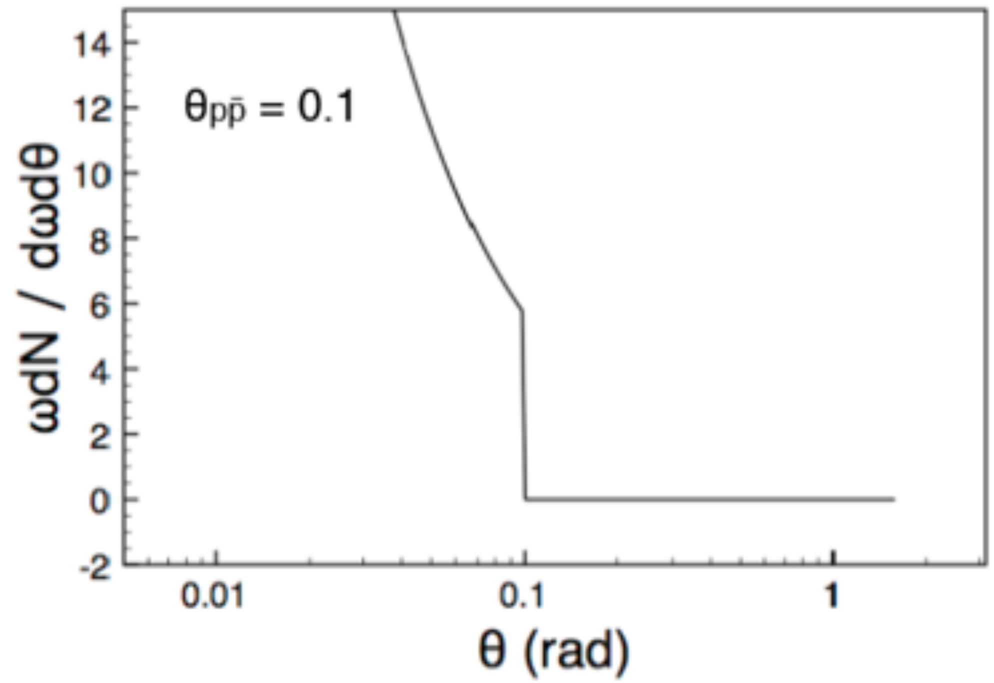
$$\omega \frac{dN^{\text{tot}}}{d^3\vec{k}}\bigg|_{\omega\to 0} = \omega \frac{dN^{\text{vac}}}{d^3\vec{k}}\bigg|_{\omega\to 0} + \omega \frac{dN^{\text{med}}}{d^3\vec{k}}\bigg|_{\omega\to 0}$$

$$= \frac{\alpha_s C_F}{(2\pi)^2}(\mathcal{P}_{in} + \mathcal{P}_{out})$$

$\Delta_{med} \to 0$ "Switching off" the medium

$$\mathcal{P}_{in} = (1 - \Delta_{med})(\mathcal{R}_{in} - \mathcal{J}) \to \mathcal{P}_{in}^{vac}$$

$$\mathcal{P}_{out} = (\mathcal{R}_{out} - \mathcal{J}) + \Delta_{med}\mathcal{J} \to \mathcal{P}_{out}^{vac}$$



Restoration of the vacuum coherence pattern !!!!

The full gluon spectrum: Soft limit and probabilistic interpretation

$$\omega \frac{dN^{\text{tot}}}{d^3\vec{k}}\bigg|_{\omega\to 0} = \omega \frac{dN^{\text{vac}}}{d^3\vec{k}}\bigg|_{\omega\to 0} + \omega \frac{dN^{\text{med}}}{d^3\vec{k}}\bigg|_{\omega\to 0}$$

$$= \frac{\alpha_s C_F}{(2\pi)^2}\left(\mathcal{P}_{in} + \mathcal{P}_{out}\right)$$

$\Delta_{med} \to 1$ "opaque" medium

$$\mathcal{P}_{in} = \left(1 - \Delta_{med}\right)\left(\mathcal{R}_{in} - \mathcal{J}\right) \to 0$$

$$\mathcal{P}_{out} = \left(\mathcal{R}_{out} - \mathcal{J}\right) + \Delta_{med}\mathcal{J} \to \mathcal{R}_{out}$$

- Suppression of the initial state radiation!!

The full gluon spectrum: Soft limit and probabilistic interpretation

$$\omega \frac{dN^{\text{tot}}}{d^3\vec{k}}\bigg|_{\omega\to 0} = \omega \frac{dN^{\text{vac}}}{d^3\vec{k}}\bigg|_{\omega\to 0} + \omega \frac{dN^{\text{med}}}{d^3\vec{k}}\bigg|_{\omega\to 0}$$

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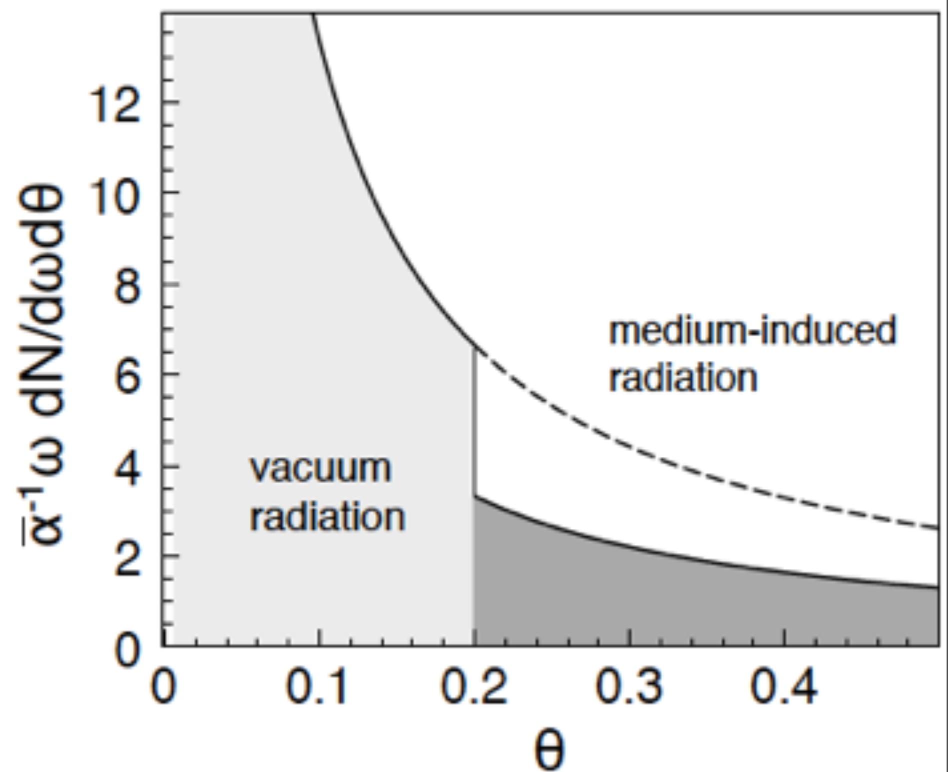

- Suppression of the initial state radiation!!
- Total decoherence of the final state radiation: large angle emissions !!

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Conclusions and outlook

- We study interferences between initial and final state radiation in a QCD medium.
- A probabilistic interpretation is found in the incoherent, coherent and soft limit of the gluon spectrum.
- The setup studied here might have phenomenological consequences in HIC:
  - Suppression of the initial state radiation (ISR)
  - Look for observables sensitives to ISR: information about evolution eqs.
- **Future work (stay tuned):**
  - Numerical results for the dilute regime case
  - Analytical studies for an opaque medium (multiple scatterings).
  - Use these results for phenomenological studies...

Backup slides

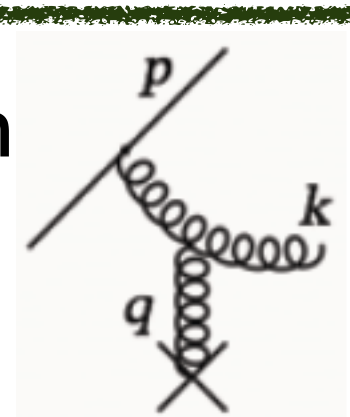
Opacity expansion: N=1 amplitude

For a parton created inside the medium, it describes two main physical processes of medium induced gluon radiation:

$$\mathcal{M}^a_{\lambda,q(1)} = 2\,ig^2 \int \frac{d^2\boldsymbol{q}}{(2\pi)^2} \int_0^\infty dx^+ \left[T\cdot \mathcal{A}_{\text{med}}(x^+,\boldsymbol{q})\right]^{ab} Q^b_q$$

$$\times \left\{ \frac{\boldsymbol{\kappa}-\boldsymbol{q}}{(\boldsymbol{\kappa}-\boldsymbol{q})^2} - \boldsymbol{L}\, \exp\left[i\frac{(\boldsymbol{\kappa}-\boldsymbol{q})^2}{2k^+}x^+\right]\right\}\cdot \boldsymbol{\epsilon}_\lambda$$

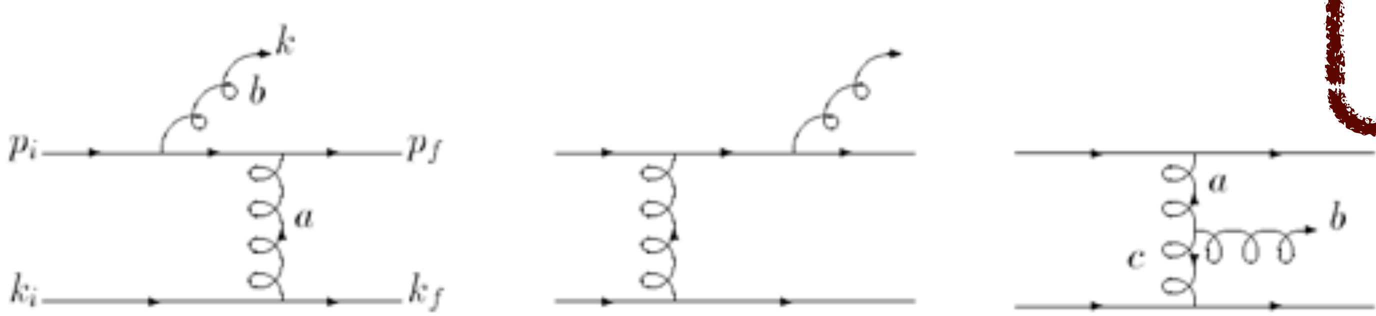
Hard emission with rescattering



Lipatov vertex

$$L = \frac{\kappa - q}{(\kappa-q)^2} - \frac{\kappa}{\kappa^2}$$

Medium induced emission off an on-shell particle



GLV Spectrum

$$\omega \frac{dN_q^{\rm GLV}}{d\omega d^2k_\perp} = \frac{8\,\alpha_s C_F\,\hat{q}}{\pi} \int \frac{d^2q_\perp}{(2\pi)^2} \int_0^L dt\, \frac{1-\cos\frac{(k_\perp - q_\perp)^2}{2\omega}t}{(q_\perp^2+\mu_D^2)^2} \frac{k_\perp \cdot q_\perp}{k_\perp^2 (k_\perp - q_\perp)^2}$$

☑ Gluon spectrum is infrared and collinearly safe

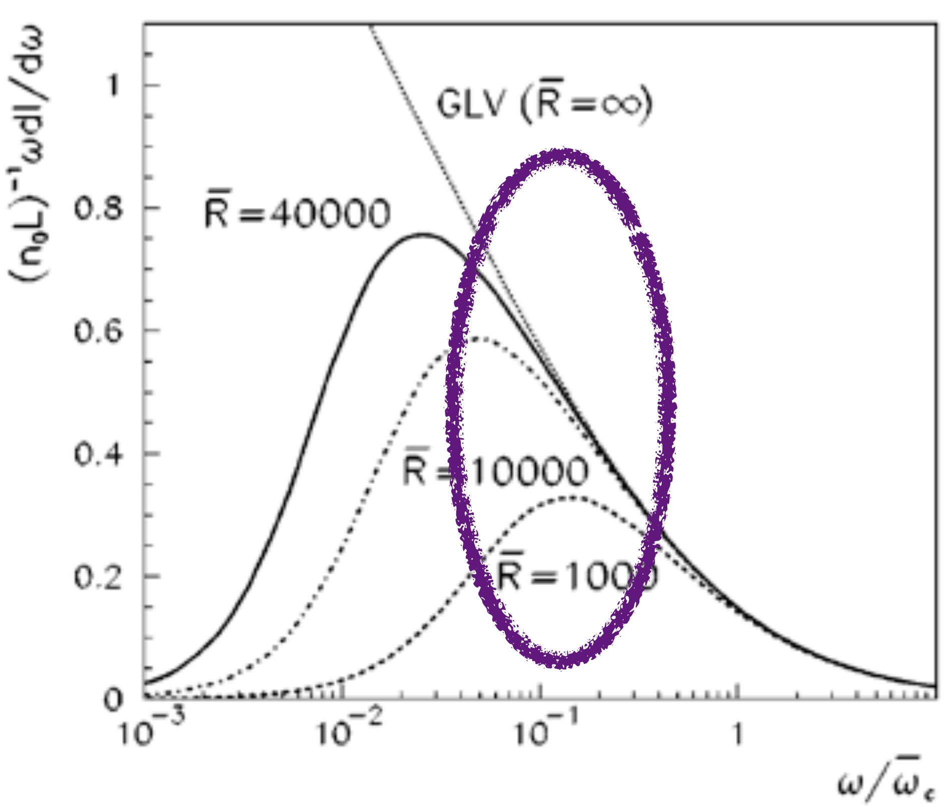
☑ Formation time effect:

Time dependent part: $1-\cos(L/t_f)$

$$L/t_f \ll 1 \quad \Rightarrow \quad dN_q^{GLV} \to 0$$

➪ Long formation times are suppressed

☑ Landau Migdal Pomeranchuk effect



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$$t_f = \frac{2\omega}{k_\perp^2}$$

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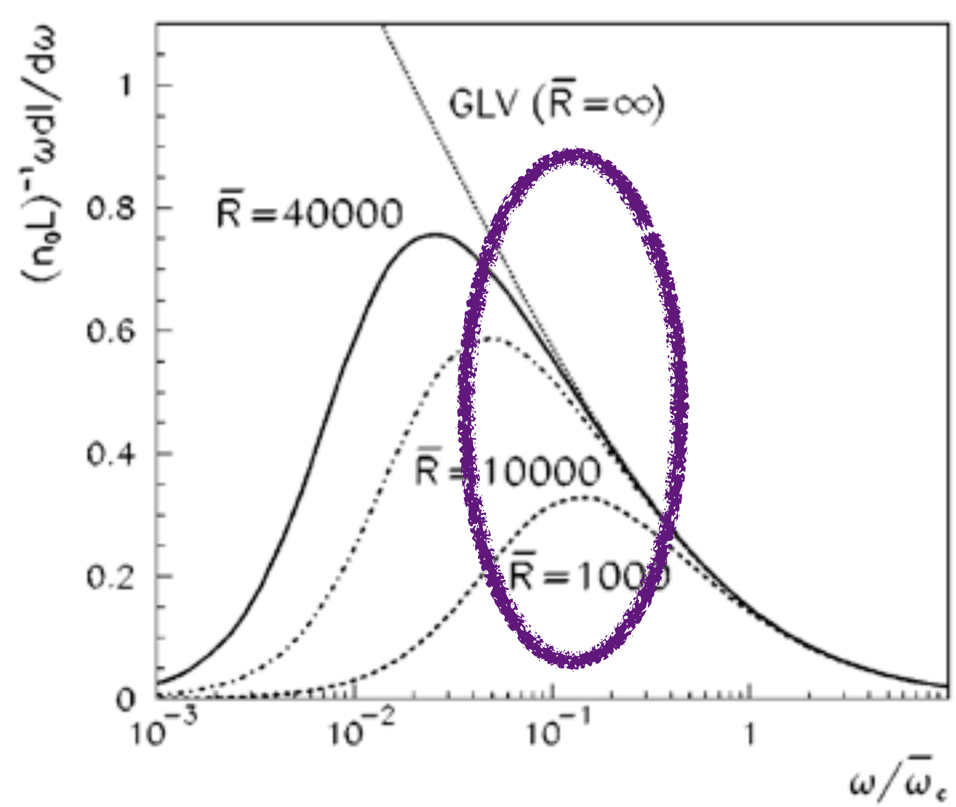

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Incoherent limit: $\tau_f \ll L$

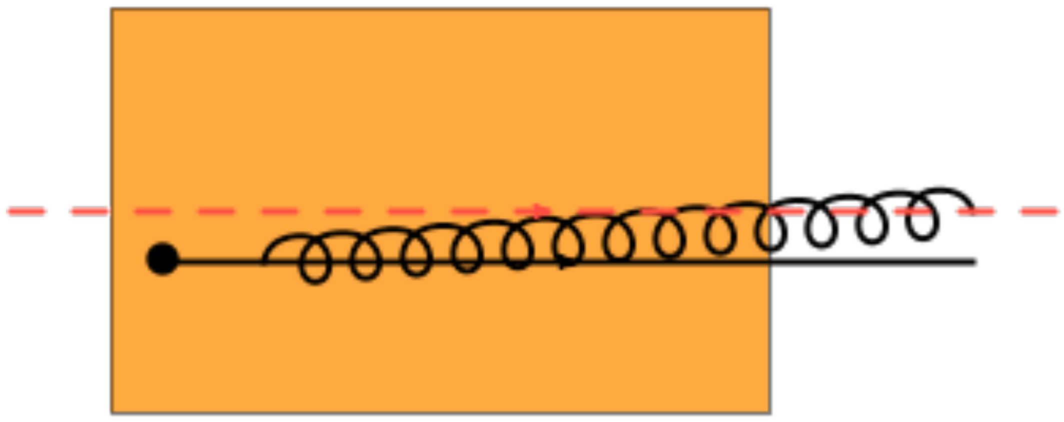
$$\omega \left.\frac{dN_q^{\rm GLV}}{d\omega d^2 k_\perp}\right|_{\tau_f \ll L} = \frac{4\,\alpha_s C_F\,\hat{q} L^+}{\pi} \int_{\mathcal{V}(\mathbf{q})} \left[\mathbf{L}^2 + \frac{1}{(\mathbf{k}-\mathbf{q})^2} - \frac{1}{\mathbf{k}^2} \right]$$

☆ Induced radiation of an asymptotic color charge (Gunion- Bertsch)

☆ Bremstrahlung of an accelerated color charge

$$\mathbf{L}^2 = \frac{\mathbf{q}^2}{\mathbf{k}^2 (\mathbf{k}-\mathbf{q})^2}$$

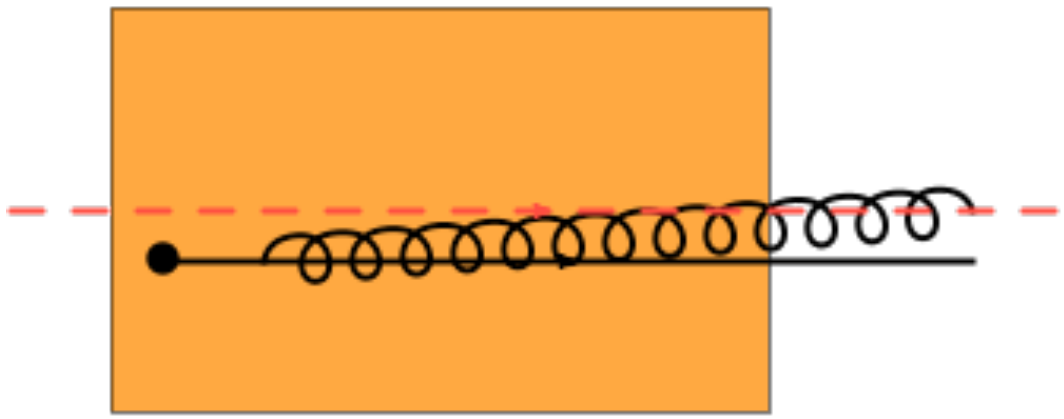
The LPM effect



$$t_{form} > L$$

Gluon has long formation time = is indistinguishable from the quark for a long time → as if created after the medium

The LPM effect



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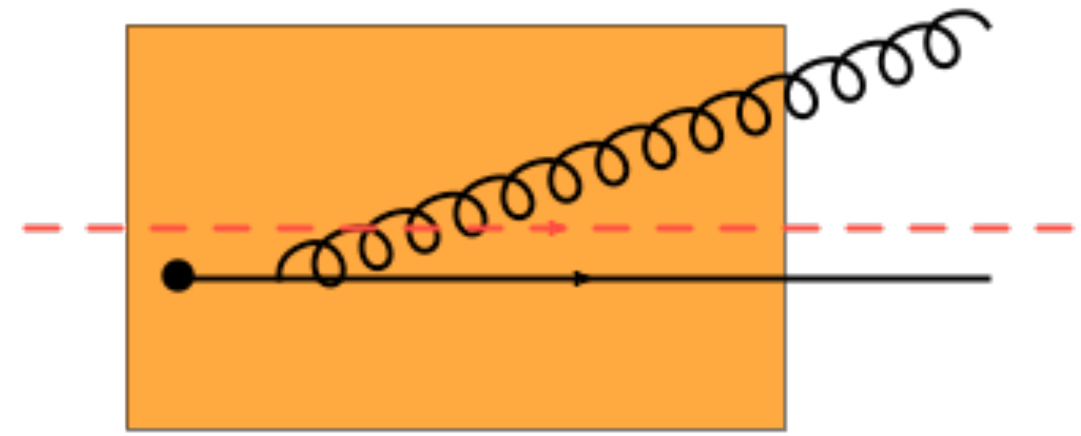

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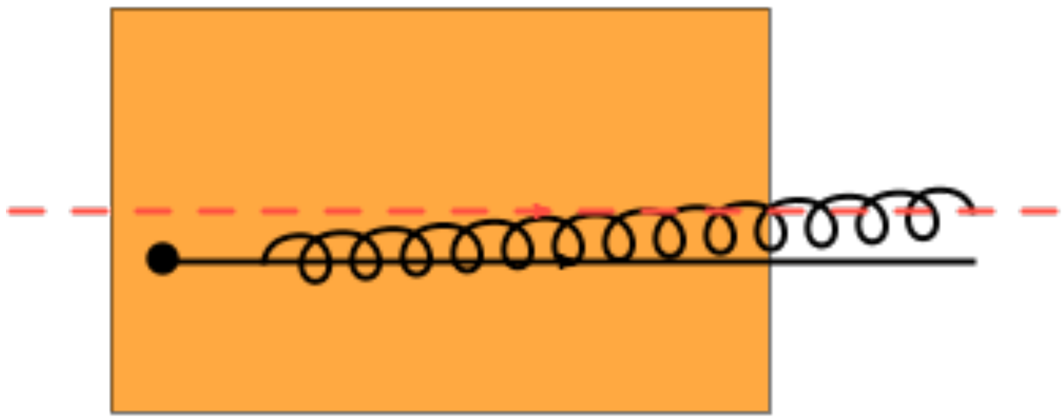
Gluon has short formation time → starts interacting with the medium right away

The LPM effect



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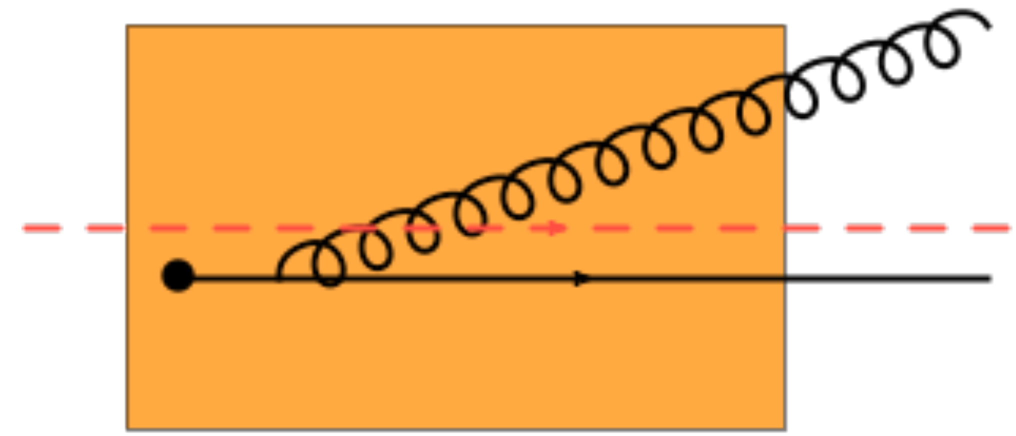

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Gluon has short formation time → starts interacting with the medium right away

Medium-induced rad suppressed!

Brief overview of the antenna in a QCD medium

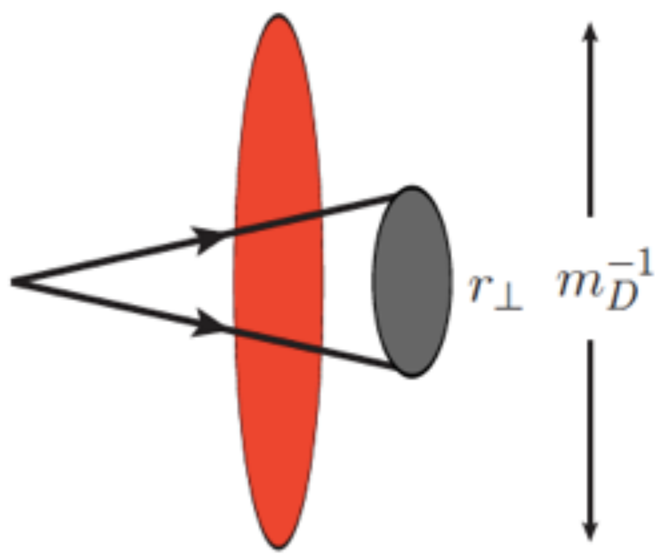
Mehtar-Tani, Salgado, Tywoniuk, 2011

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

$r_\perp = \theta_{qq} L^+$ Antenna Dipole size

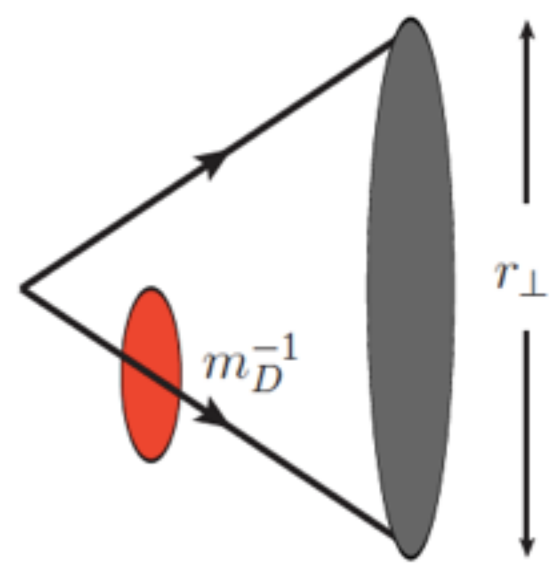
m_D Debye mass

Dipole Regime



$r_\perp \ll m_D^{-1}$

Decoherence Regime



$r_\perp \gg m_D^{-1}$

$$\Delta_{med} \equiv \frac{\hat{q}}{m_D^2}\int_0^{L^+} dx^+\left[1-\frac{r_\perp m_D x^+}{L^+}K_1\left(\frac{r_\perp m_D x^+}{L^+}\right)\right] \begin{cases} \approx \hat{q}L^+ r_\perp^2 \ln\left(\dfrac{1}{r_\perp m_D}\right) & \text{for} \quad r_\perp \gg m_D^{-1} \\ \approx \dfrac{\hat{q}L^+}{m_D^2} & \text{for} \quad r_\perp \ll m_D^{-1} \end{cases}$$

Antenna in a QCD medium: finite energies

Hard scale of the problem: $Q_{\rm hard} = \max\left(r_\perp^{-1}, Q_s, \delta\boldsymbol{k}\right)$

$k_\perp > Q_{\rm hard}$: coherence!

Mehtar-Tani, Salgado, KT JHEP 1204, 064; arXiv:1205.5739

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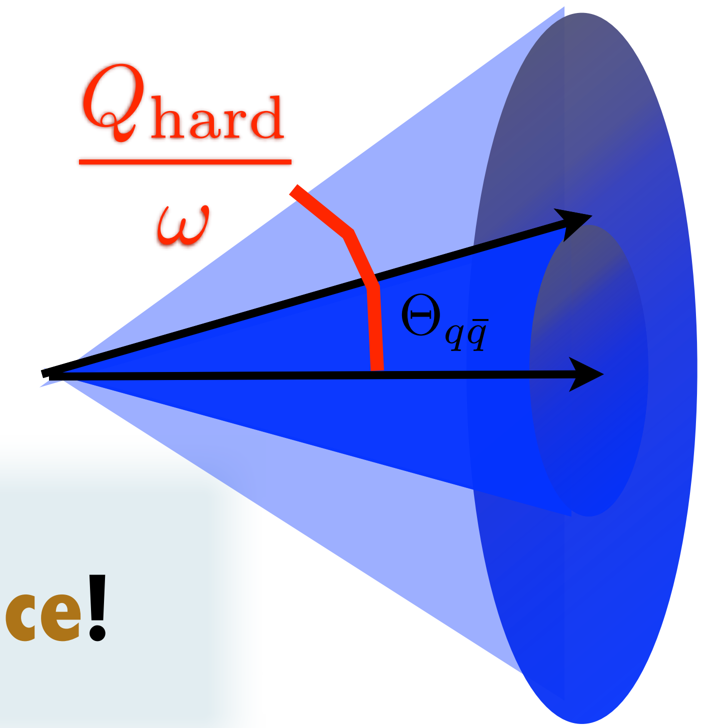
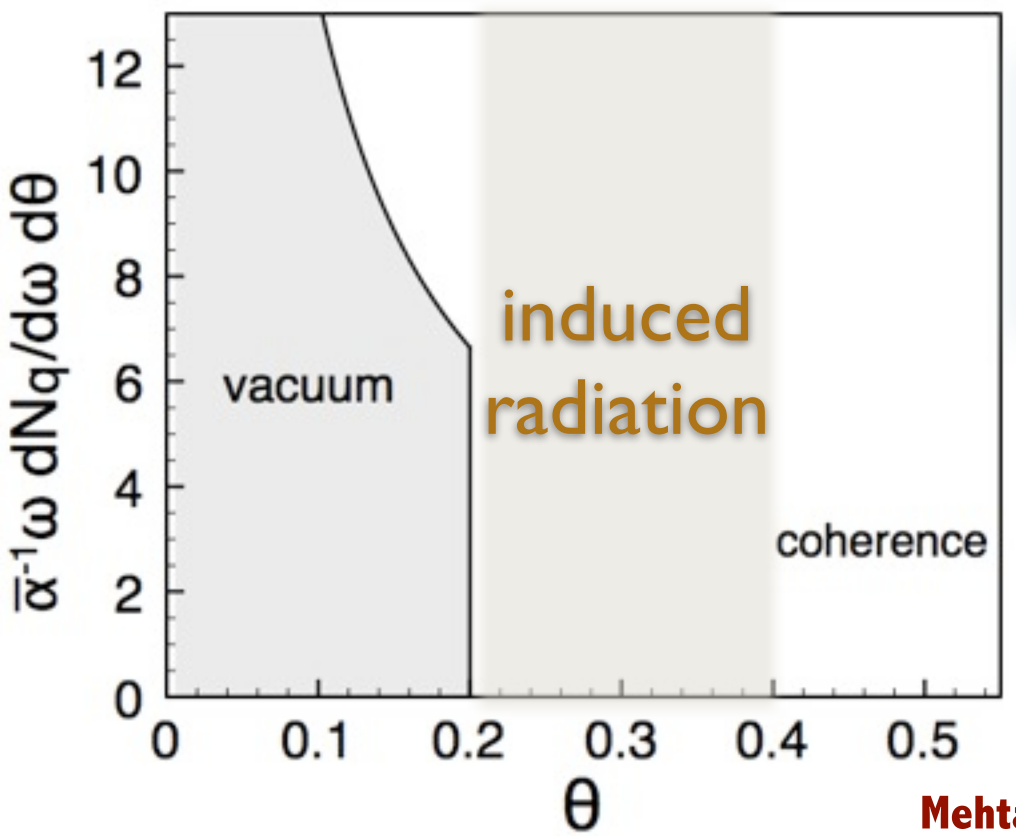


$k_\perp > Q_{\text{hard}}$: coherence!

$\theta > Q_{\text{hard}}/\omega$: coherence!



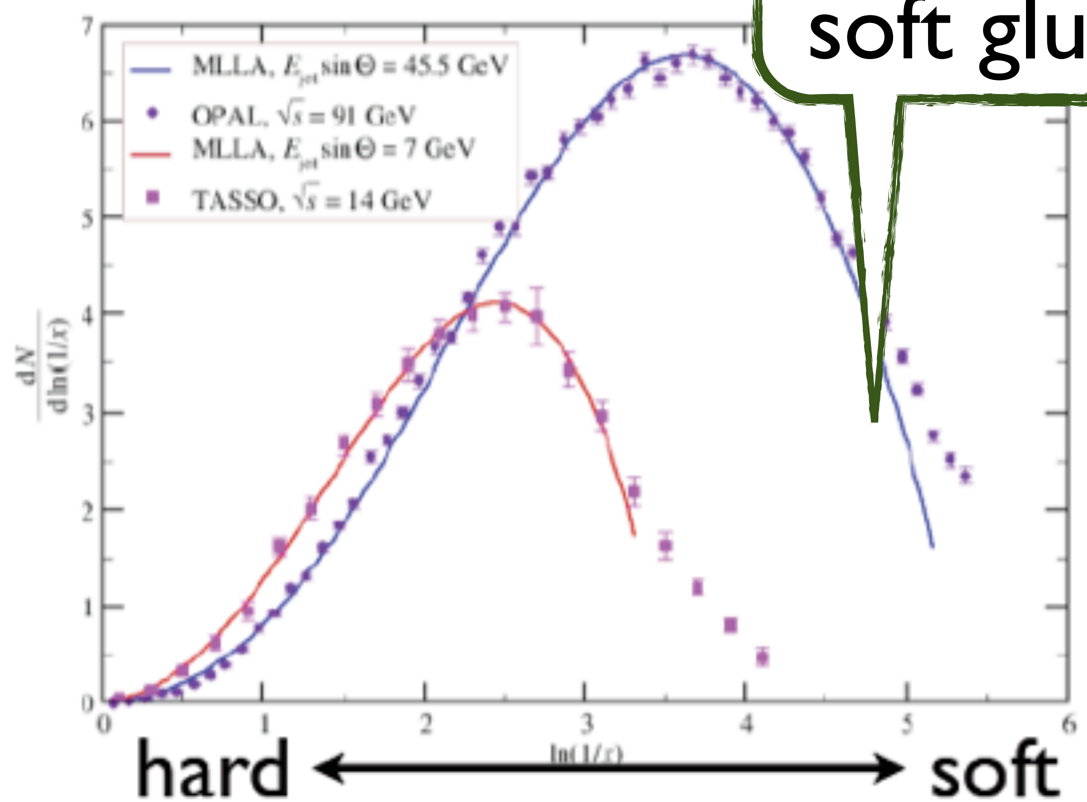
Medium scales open phase space!

- **hard bremsstrahlung necessary to restore coherence at large angles**

Mehtar-Tani, Salgado, KT JHEP 1204, 064; arXiv:1205.5739

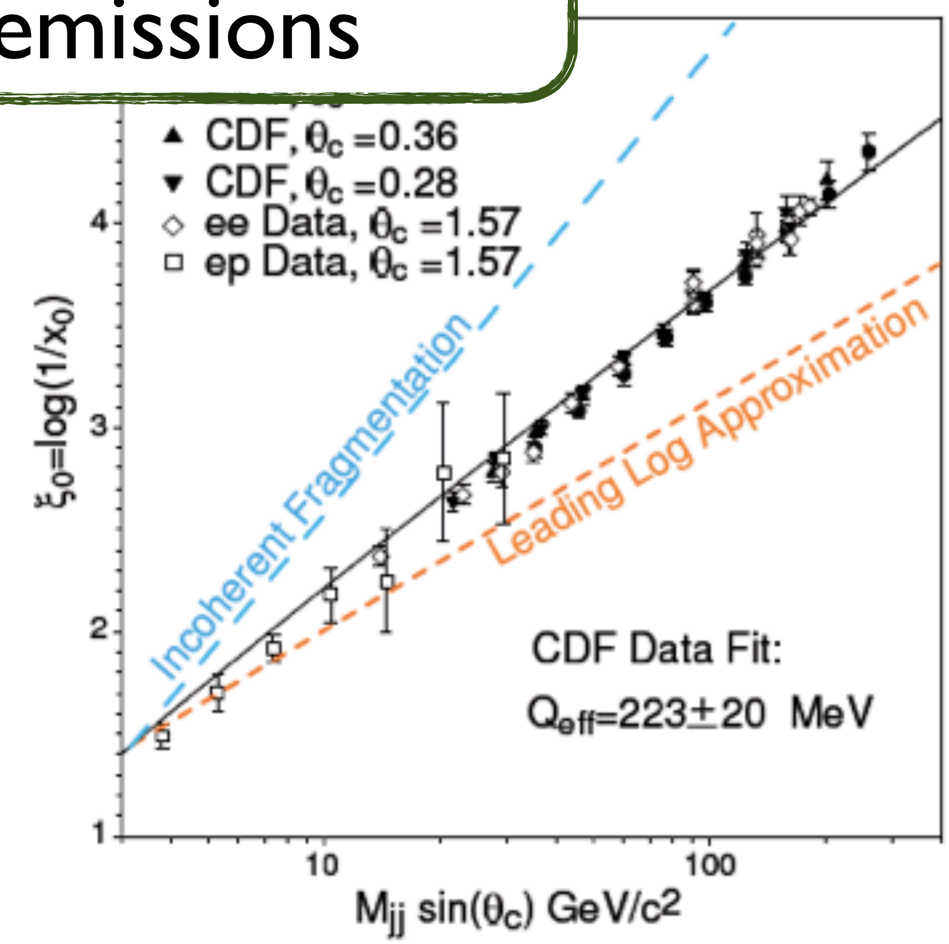
Experimental evidence of QCD coherence effects

AO limits phase space of soft gluon emissions



TASSO Collaboration, Z. Phys. C 47 (1990) 187

OPAL Collaboration, Phys. Lett. B 247 (1990) 617



Humpbacked plateau

Position of the hump