



# Prompt $\gamma$ production in heavy ion collisions

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Rencontres de Moriond QCD – La Thuile



# Outline



- Motivations
  - Parton energy loss in QCD media
- Testing medium fragmentation functions
  - Single  $\gamma$  and  $\pi^0$  production at RHIC
- Extracting medium fragmentation functions
  - Diphoton correlations at LHC
- Summary

## Reference

F. A., Aurenche, Belghobsi, Guillet, Werlen, to appear



# Motivations



Phase transition at high temperature from **hadronic matter** to **quark-gluon plasma**

A sensitive process for quark-gluon plasma formation

**Parton energy loss in dense QCD media**

Baier, Dokshitzer, Mueller, Peigné, Schiff

Gyulassy, Lévai, Vitev, Wang

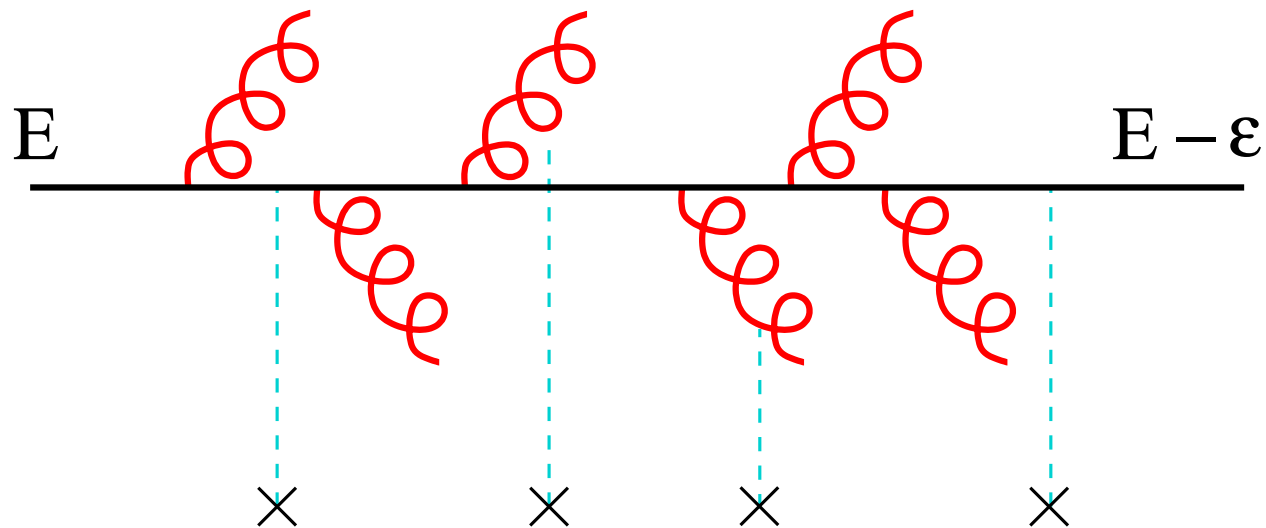
Wiedemann

Zakharov



# Parton energy loss

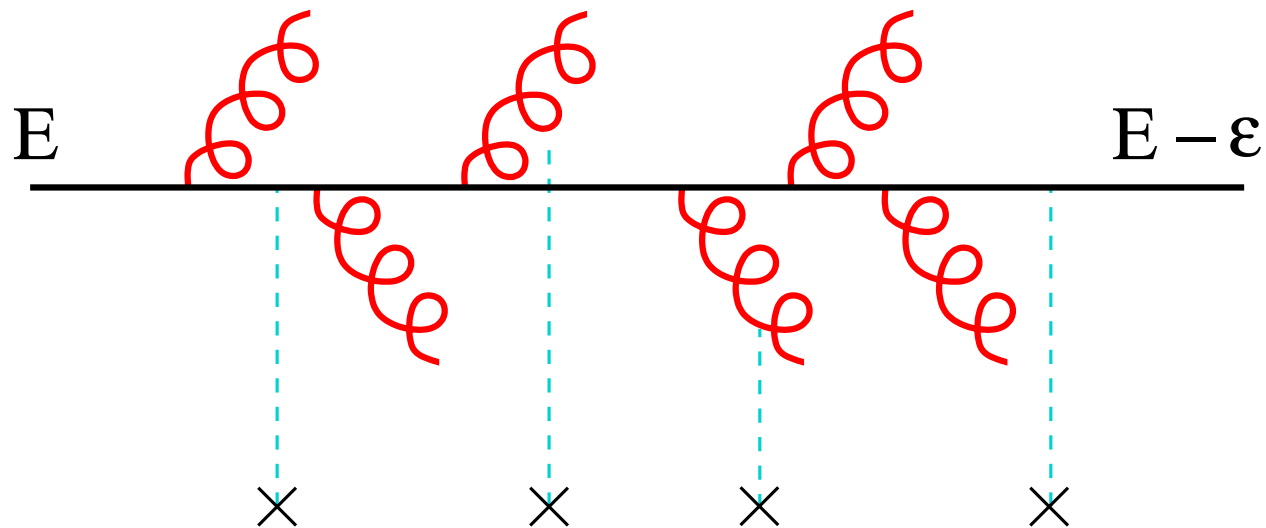
Soft multiple collisions  $\rightarrow$  strong gluon radiation



- Energy loss huge in dense media

# Parton energy loss

Soft multiple collisions  $\rightarrow$  strong gluon radiation



- How does the medium affect fragmentation ?
  - Let's have a look at photons

# Terminology

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Which photons ?



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- Prompt photons
  - Produced in NN collisions

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- Thermal photons

- Quark-Gluon Plasma radiation

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$$p_{\perp} = \mathcal{O}(T)$$



# Terminology

Which photons ?

- Prompt photons

- Produced in NN collisions

- Thermal photons

- Quark-Gluon Plasma radiation

- Decay photons

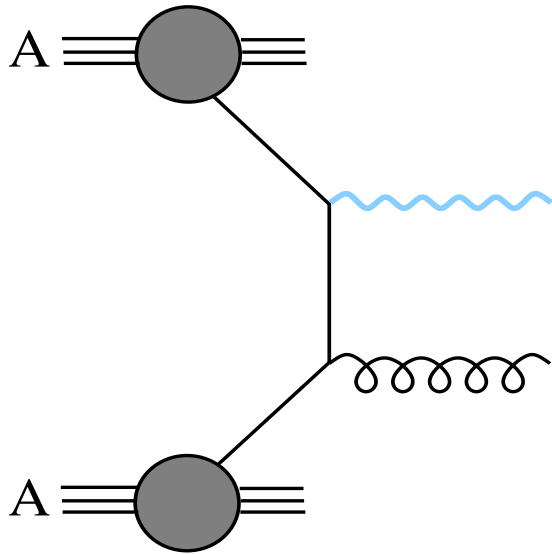
- Radiative decay

$$p_{\perp} \gg \Lambda_{QCD}$$

$$p_{\perp} = \mathcal{O}(T)$$

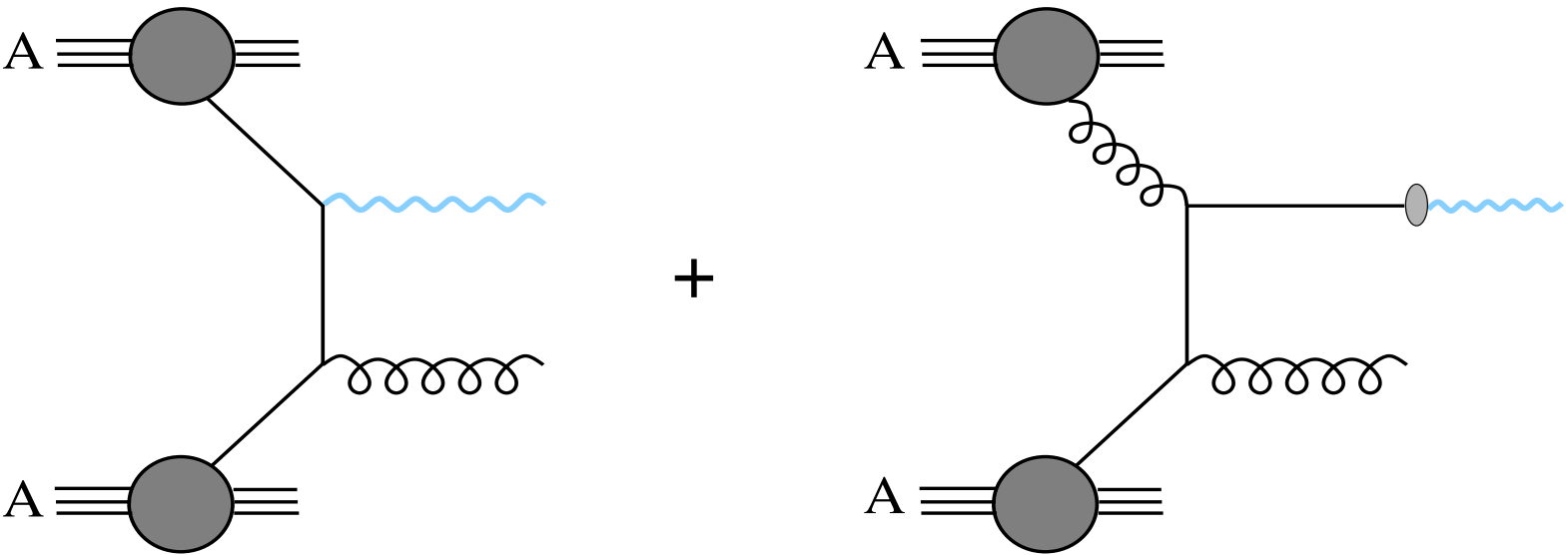
$$\pi^0 \rightarrow \gamma \gamma$$

# $\gamma$ production in QCD



$$\frac{d\sigma}{d\vec{p}_T d\eta} \simeq \sum_{i,j=q,g} \int dx_1 dx_2 F_{i/h_1}^A(x_1) F_{j/h_2}^A(x_2) \frac{d\hat{\sigma}_{ij}}{d\vec{p}_T d\eta}$$

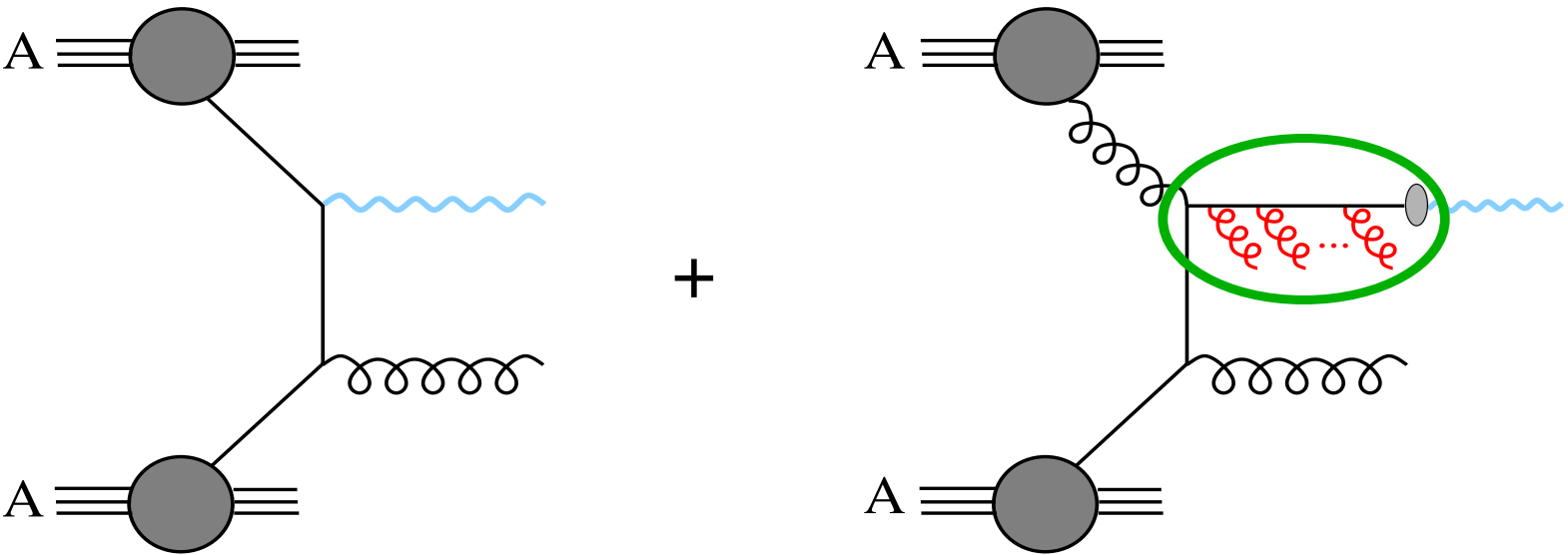
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$$+ \sum_{i,j,k=q,g} \int dx_1 dx_2 F_{i/h_1}^A(x_1) F_{j/h_2}^A(x_2) \frac{dz}{z^2} D_{\gamma/k}(z, \mu) \frac{d\hat{\sigma}_{ij}^k}{d\vec{p}_T d\eta}$$

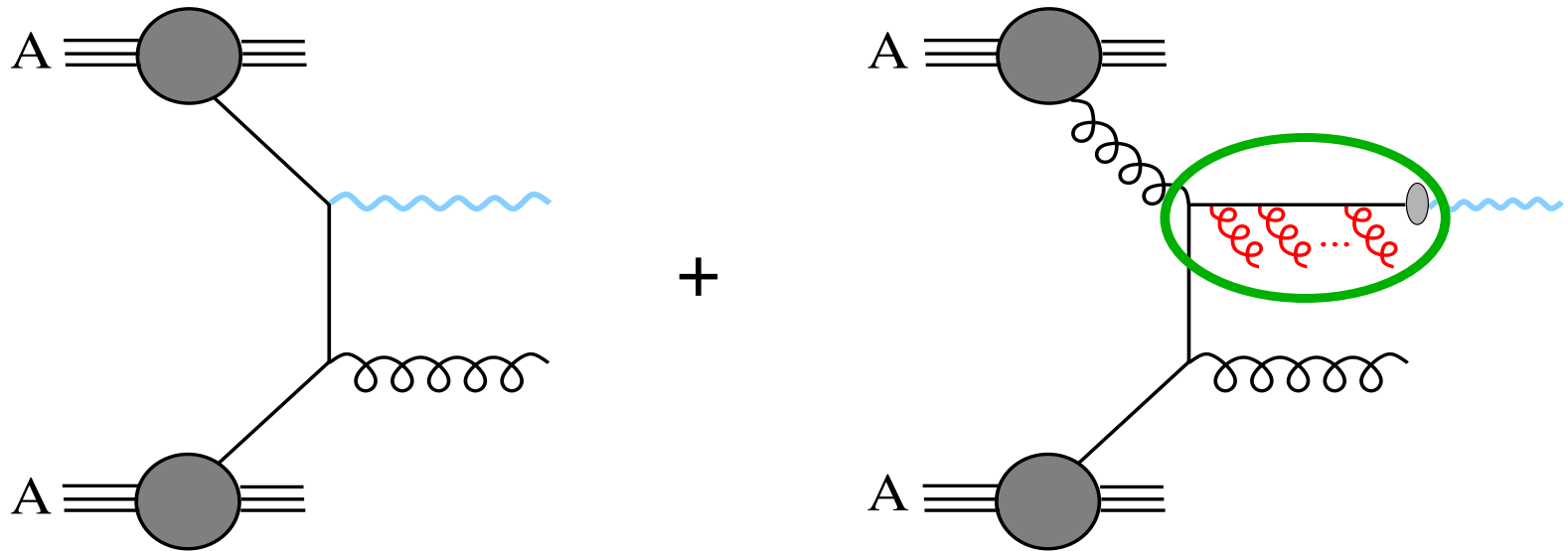
# $\gamma$ production in QCD



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$$+ \sum_{i,j,k=q,g} \int dx_1 dx_2 F_{i/h_1}^A(x_1) F_{j/h_2}^A(x_2) \frac{dz}{z^2} D_{\gamma/k}^{med}(z, \mu) \frac{d\hat{\sigma}_{ij}^k}{d\vec{p}_T d\eta}$$

# $\gamma$ production in QCD

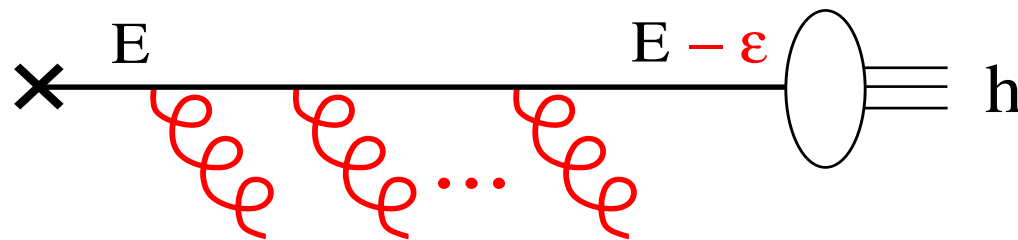


- No medium effect for the **direct** component
- **fragmentation**  $\gamma$  affected by multiple scattering
  - sensitive probe to investigate in A-A collisions

# Modified fragmentation functions



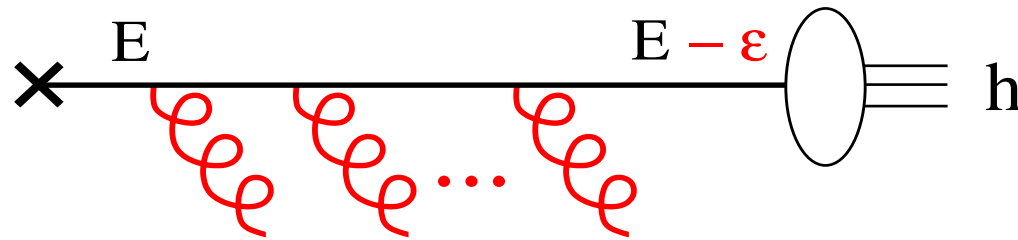
- Multiple scattering shift parton energy from  $E$  to  $E - \epsilon$   
Wang, Huang, Sarcevic (1996)



# Modified fragmentation functions



- Multiple scattering shift parton energy from  $E$  to  $E - \epsilon$   
Wang, Huang, Sarcevic (1996)



$$z D_{h/k}^{med}(z, \mu) = \int_0^{(1-z)E} d\epsilon \mathcal{P}(\epsilon, E) z^* D_{h/k}(z^*, \mu)$$

- $z^*$  defined as

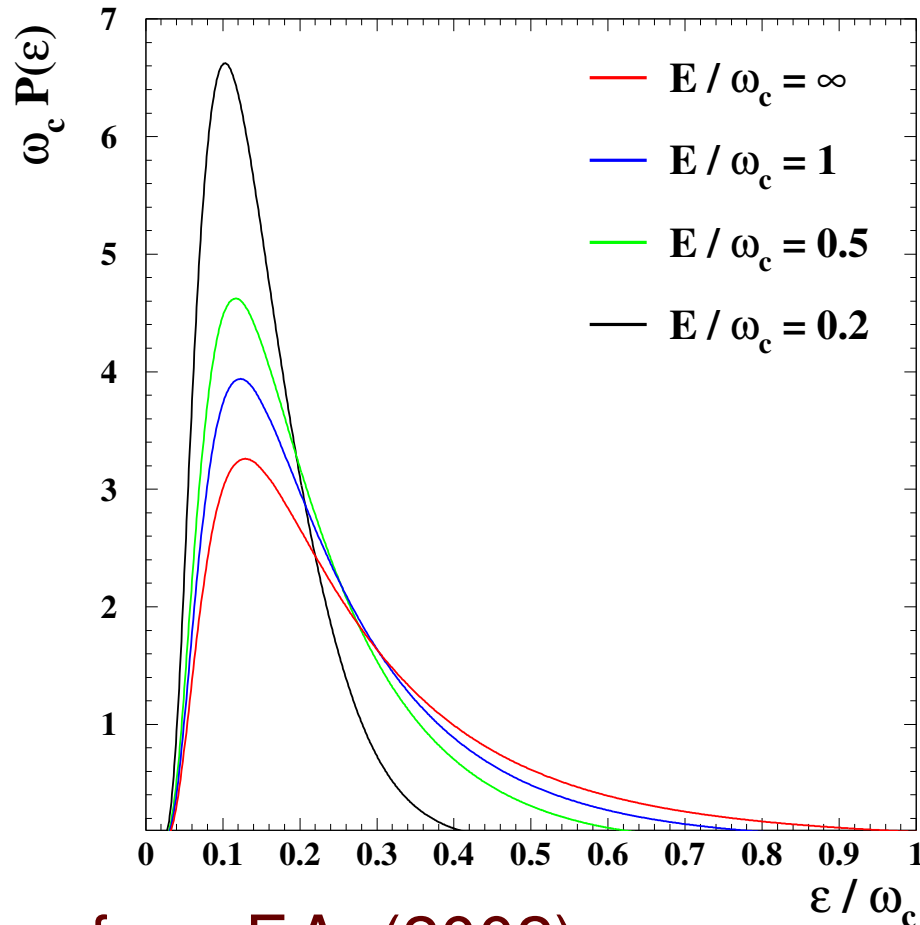
$$z^* = \frac{E_h}{E - \epsilon} = \frac{z}{1 - \epsilon/E}$$

- $\mathcal{P}(\epsilon, E)$  = quenching weight



# Quenching weight $\mathcal{P}(\epsilon, E)$

Baier, Dokshitzer, Mueller, Schiff (2001)



Relevant scale

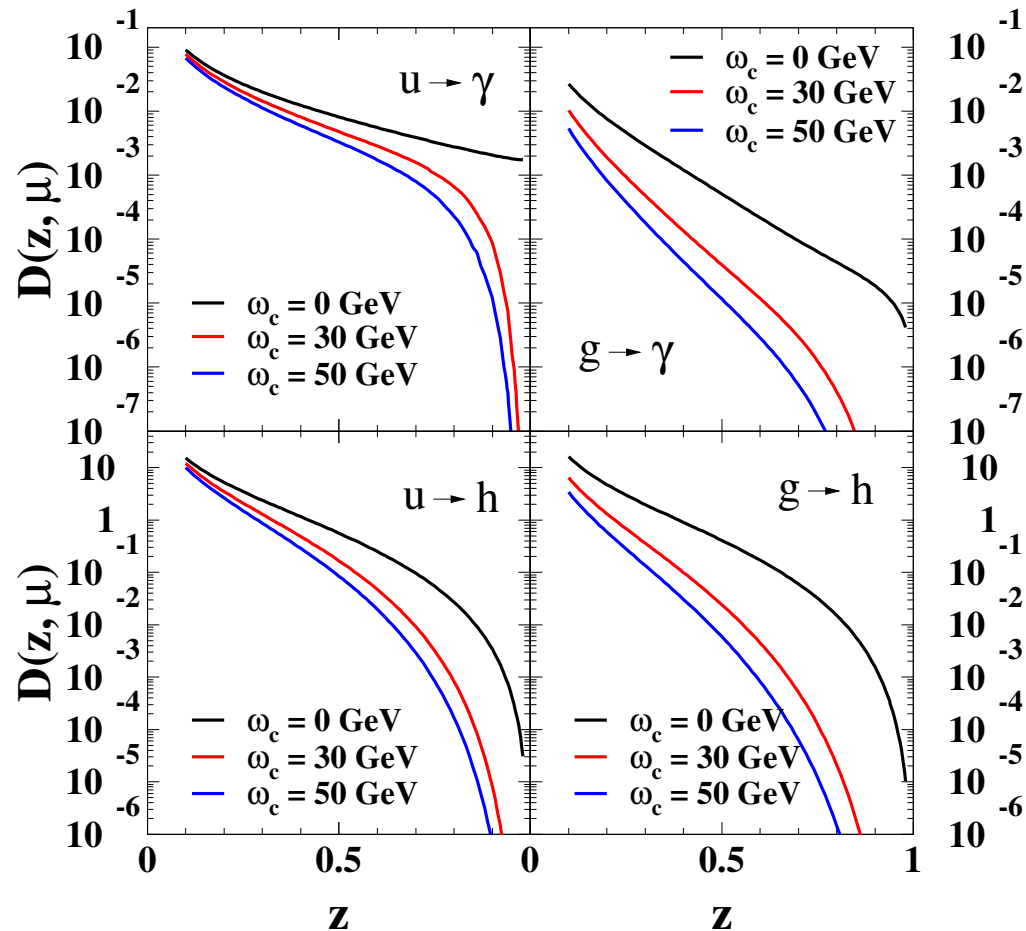
$$\omega_c = \frac{1}{2} \hat{q} L^2$$

- $\hat{q}$  : medium density
- $L$  : medium length

from F.A. (2002)



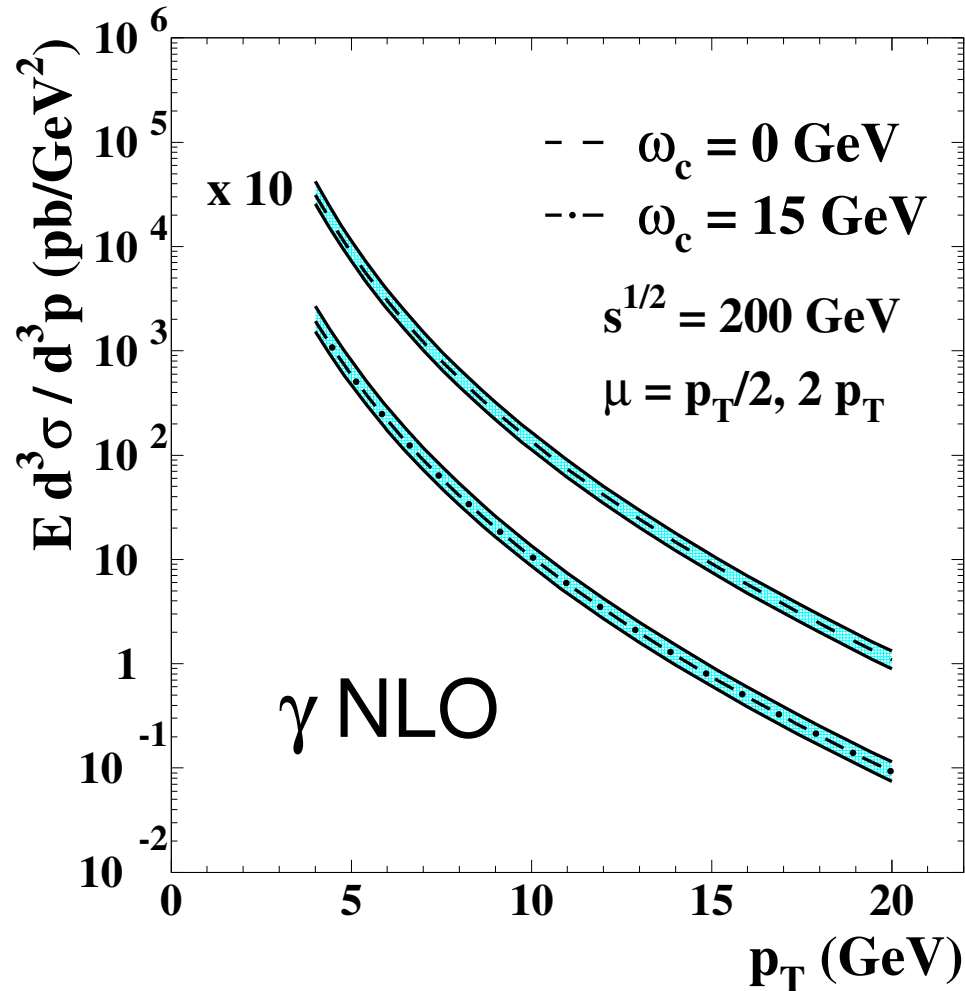
# Modified fragmentation functions



- Strong attenuation at large  $z$
- Describe successfully DIS data on nuclear targets

F.A. (2003)

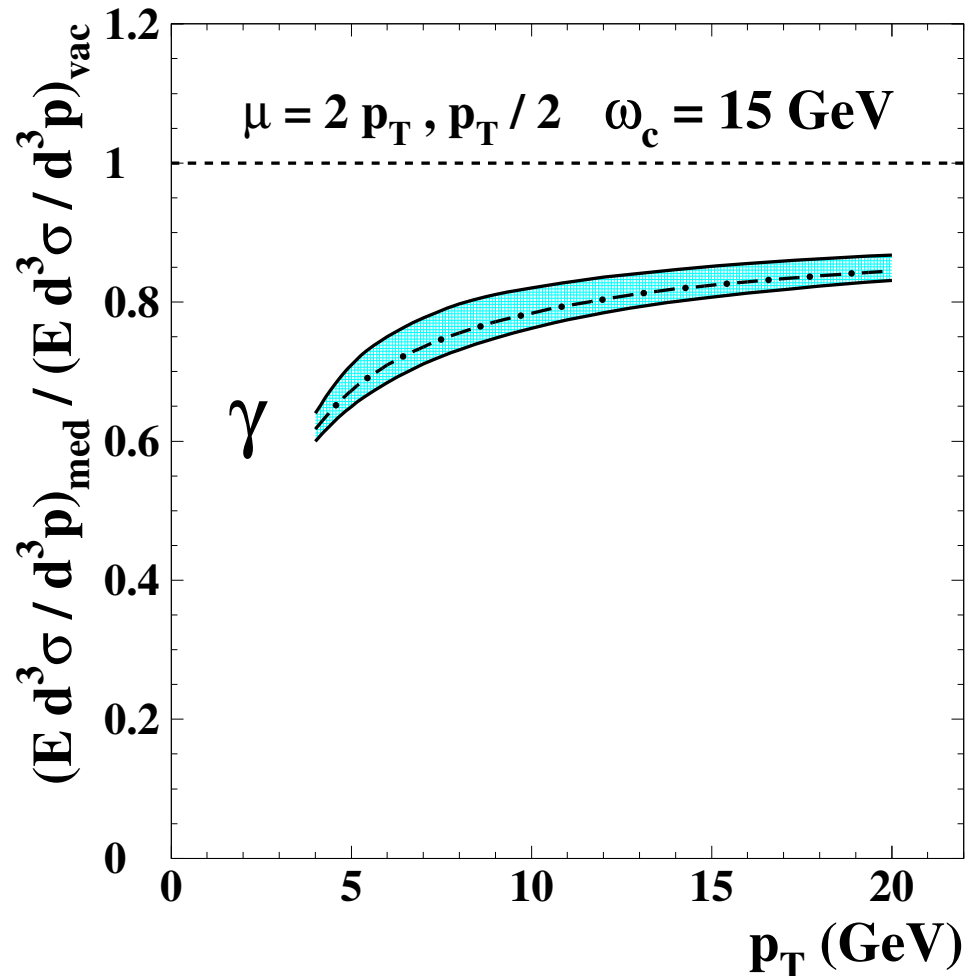
# Inclusive $\gamma$ spectra



● Slope slightly affected by the medium

● Rather small scale dependence

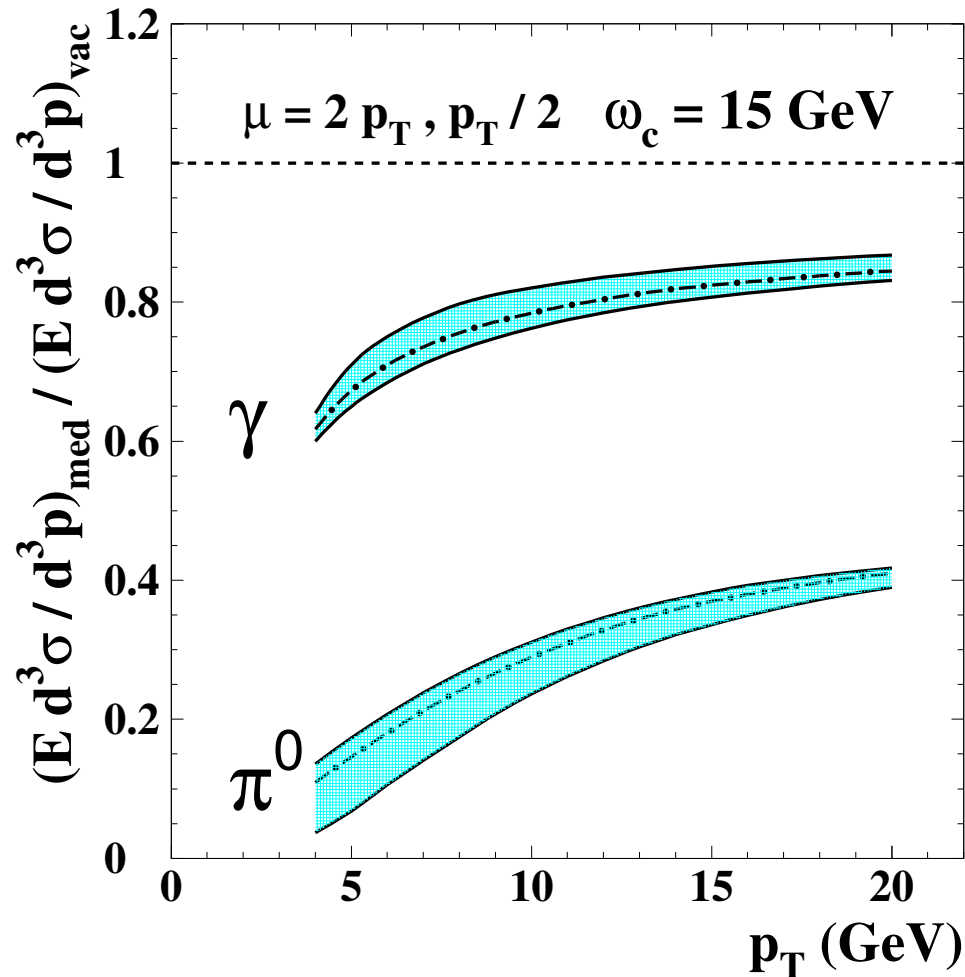
# Spectra ratios $\gamma$



● Mild increase with  $p_{\perp}$

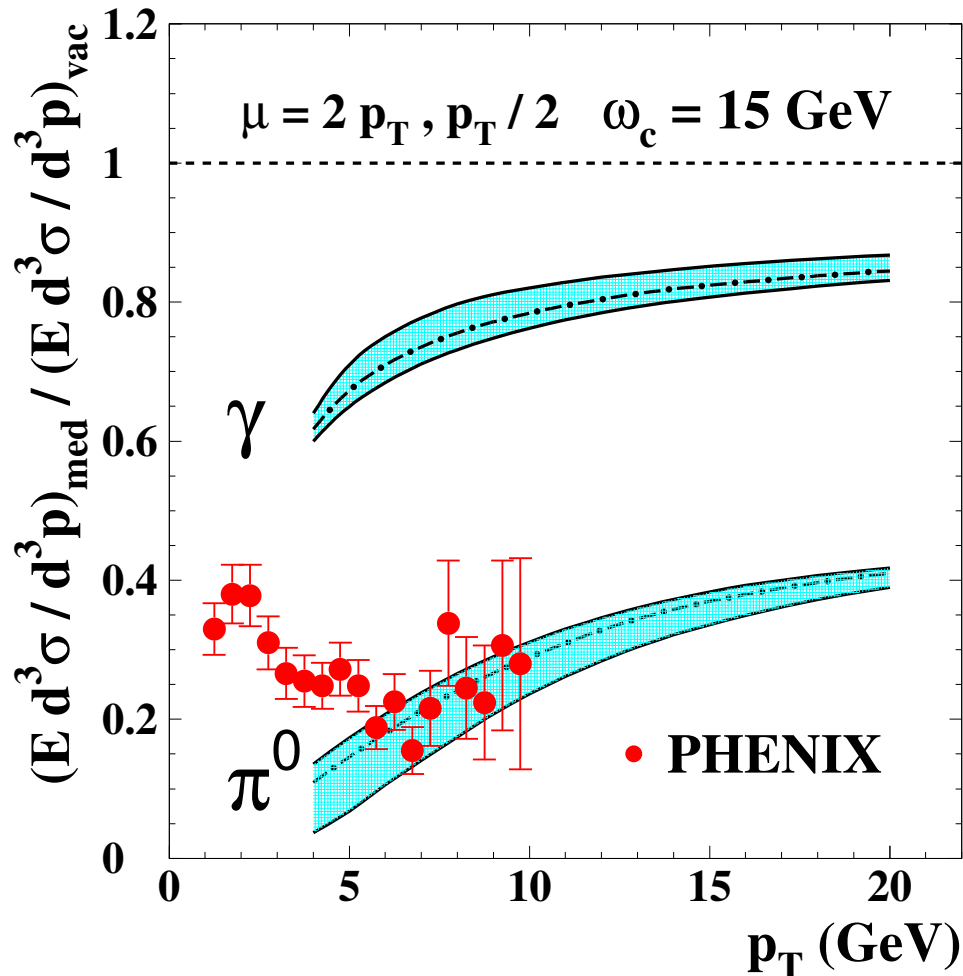
● Moderate 20 % effect at RHIC ( $\omega_c = 15 \text{ GeV}$ )

# Spectra ratios $\gamma$ vs. $\pi^0$



- Stronger suppression in the  $\pi^0$  channel

# Spectra ratios $\gamma$ vs. $\pi^0$



• Stronger suppression in the  $\pi^0$  channel

• Good agreement with PHENIX high  $p_{\perp}$   $\pi^0$  data

# Limitation

Single inclusive spectra

$$\frac{d\sigma}{d\vec{p}_T d\eta} \propto \int dz \frac{1}{z^2} D_{\gamma/k}^{med}(z, \mu)$$

do NOT determine “directly” medium frag. functions

# Limitation

Single inclusive spectra

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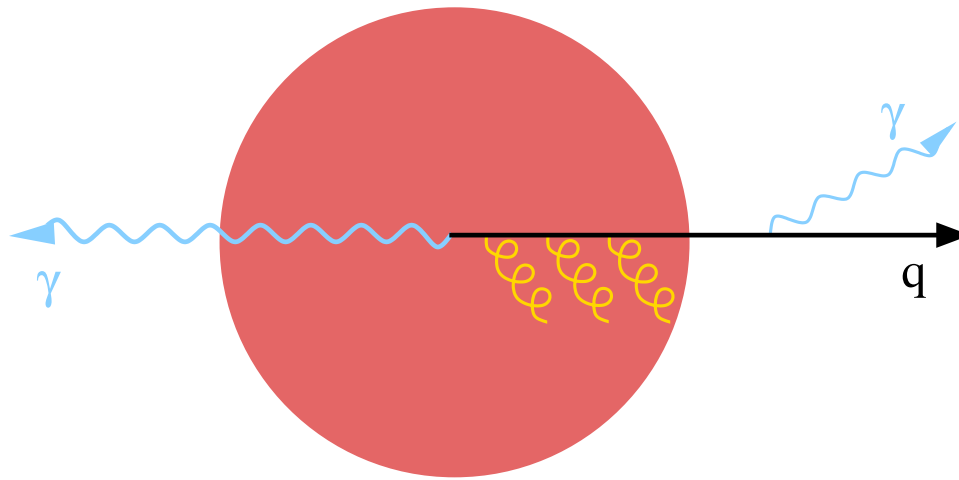
- How to fix  $z$  ?

Wang, Huang, Sarcevic (1996)

- **Diphoton production**

# Diphoton production

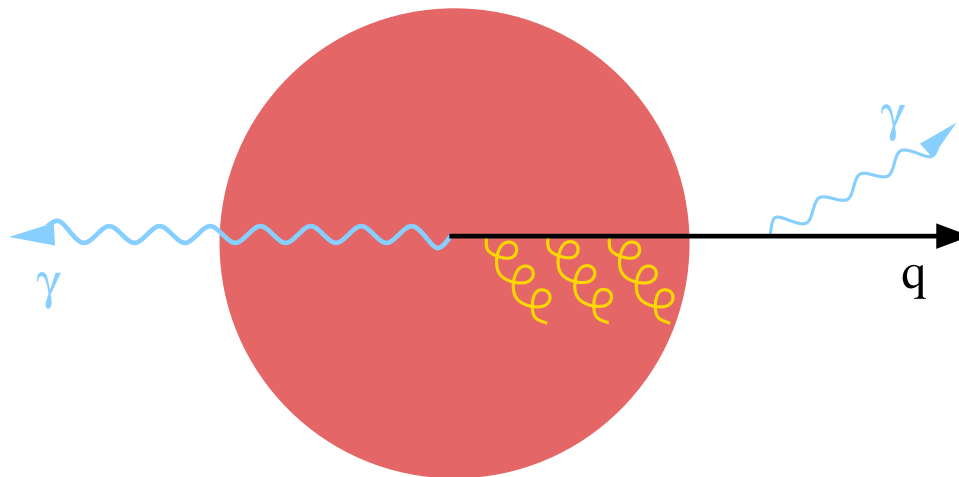
To leading order in  $\alpha_s$





# Diphoton production

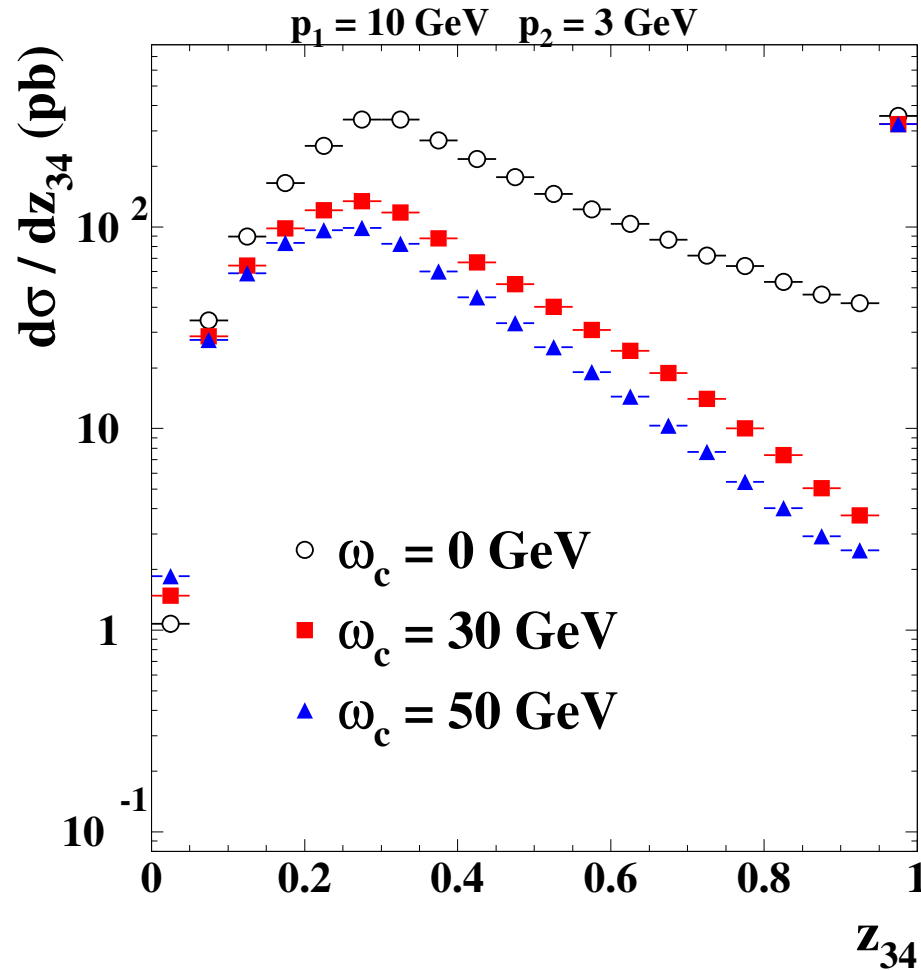
To leading order in  $\alpha_s$



- “Direct” measurement of  $z$

$$z_{34} \equiv -\frac{\vec{p}_{T3} \cdot \vec{p}_{T4}}{|\vec{p}_{T3}|^2} \simeq z$$

# $\gamma\gamma$ correlations



● Reminiscent of fragmentation functions  $D_{h/k}(z, \mu)$

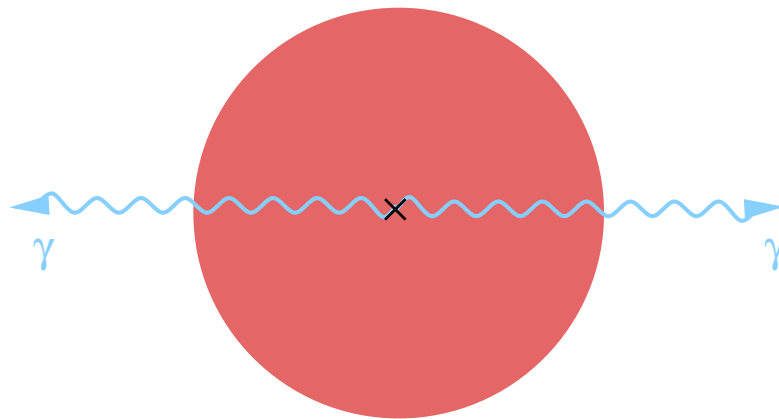
● Noticeable effects at LHC

# Caveats

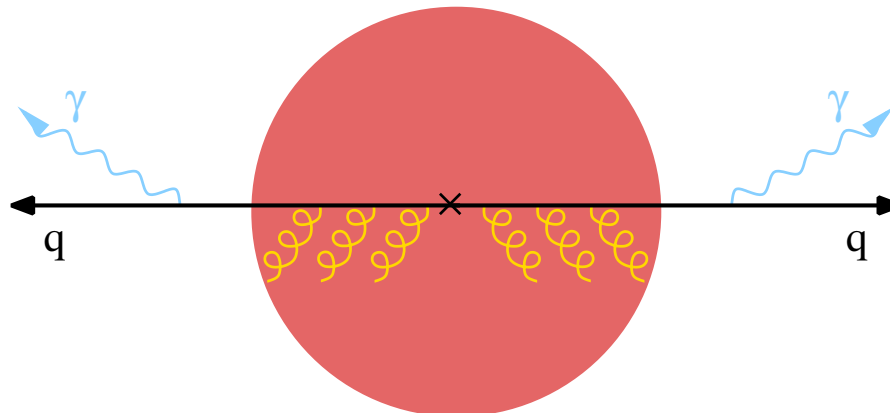


## ● “Background”

direct



2 frag.



# Caveats



- “Background”
- NLO corrections
- Infrared sensitivity
- $\gamma$  identification ( $\pi^0 \rightarrow \gamma\gamma$ )
- Low cross sections



# Caveats



- “Background”
- NLO corrections
- Infrared sensitivity
- $\gamma$  identification ( $\pi^0 \rightarrow \gamma\gamma$ )
- Low cross sections
  - $\gamma \pi^0$  correlations look promising
  - No direct component
  - Good identification
  - $(\alpha_s/\alpha)$  larger cross sections



# Summary



- $\gamma$  sensitive probe of parton energy loss
  - Medium modified  $q, g \rightarrow \gamma$  fragmentation functions
- Inclusive  $\gamma$  and  $\pi^0 p_{\perp}$  spectra at RHIC
  - Moderate effect in the  $\gamma$  channel
  - Good description of PHENIX data in the  $\pi^0$  sector
- $\gamma\gamma$  and  $\gamma\pi^0$  promising tool at LHC
  - Determination of modified fragmentation functions

