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Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

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Prompt photon production from RHIC to LHC

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Prompt photon production from RHIC to LHC

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CERN

Outline

- Motivations
  - why prompt photons and how to use them
- Single inclusive spectra
  - pQCD reference
  - quenching
- $\gamma - \pi^0$ correlations
  - definitions
  - probing fragmentation functions

[FA, Aurenche, Belghobsi, Guillet, JHEP 11 (2004) 009]
[FA, hep-ph/0601075]

Which hard probes

Schematically

1. Interacting probes

2. Non-interacting probes

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   - sensitive to dense medium formation
     - energy loss, Debye screening

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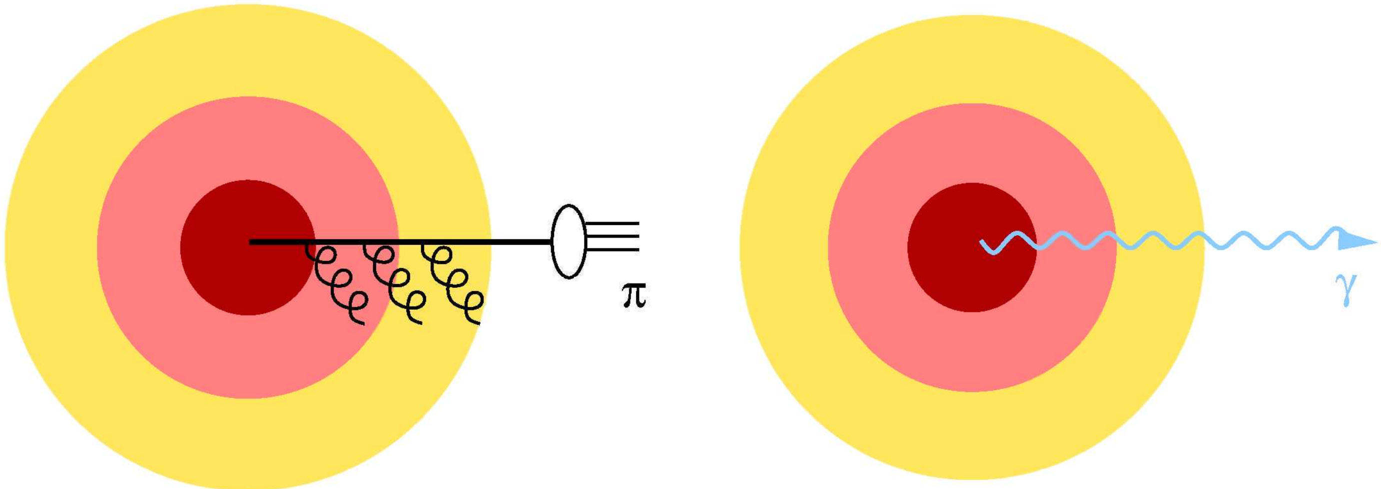
Let’s compare interacting vs. non-interacting probes !

Strategy

Two possibilities

1. Single-inclusive production



Strategy

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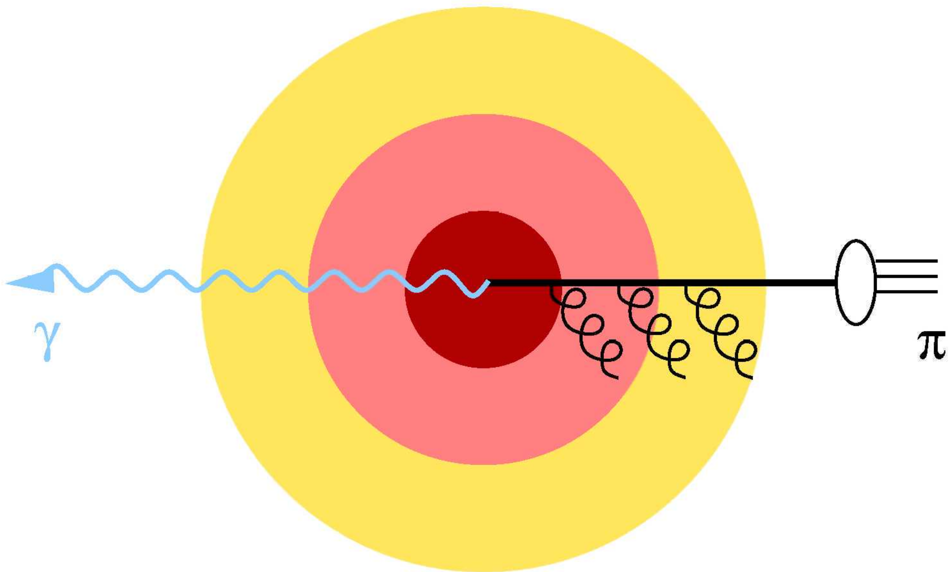
2. Double-inclusive production



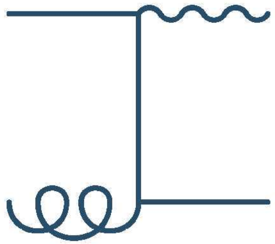
Terminology

Many different photons

- Prompt photons $p_\perp \gg \Lambda_{\rm QCD}$
  - produced in the binary NN collisions
- Thermal photons $p_\perp = \mathcal{O}\left(T\right)$
  - quark-gluon plasma radiation
- Background photons all $p_\perp$
  - π^0 radiative decays

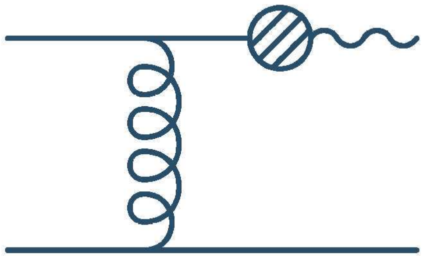
pQCD

- Direct contribution ("Drell–Yan like")



$$\mathrm{d}\sigma \sim f_i^{p,\mathrm{A}}(x_1)\, f_j^{p,\mathrm{A}}(x_2)\, \hat{\sigma} = \mathcal{O}\left(\alpha\, \alpha_s\right)$$

- Fragmentation contribution ("jet like")



$$\mathrm{d}\sigma \sim f_i^{p,\mathrm{A}}(x_1)\, f_j^{p,\mathrm{A}}(x_2)\, \hat{\sigma}\, D_{\gamma/k} = \mathcal{O}\left(\alpha_s^2\right) D_{\gamma/k} = \mathcal{O}\left(\alpha\, \alpha_s\right)$$

pQCD

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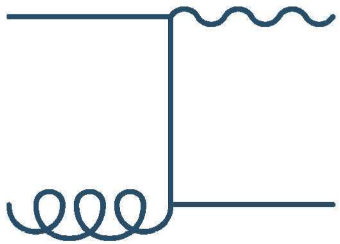

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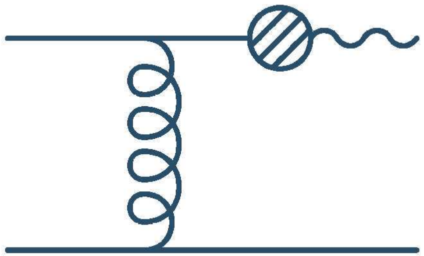

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The produced medium could – in principle –

affect prompt photon production

Direct vs. fragmentation

- Distinction between direct and fragmentation through
  - isolation criteria (w/o hadronic activity)
  - kinematics

Direct vs. fragmentation

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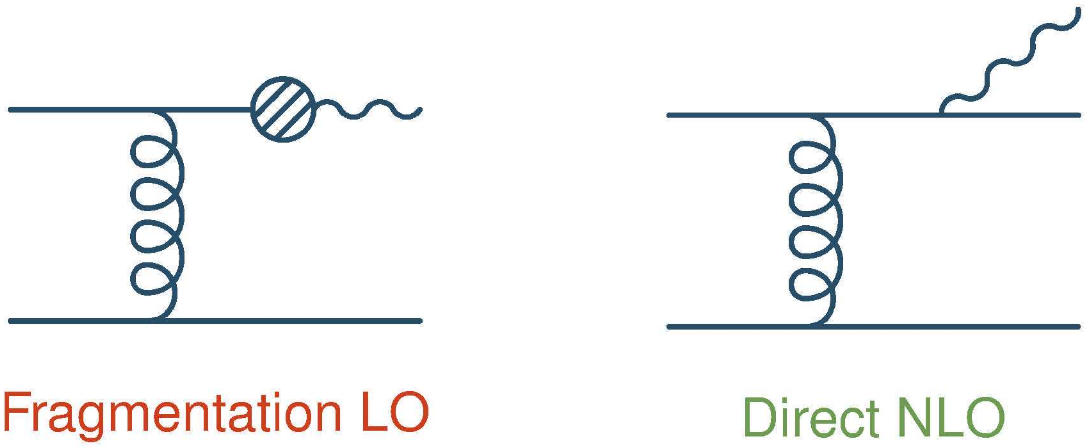
- Arbitrary distinction at NLO

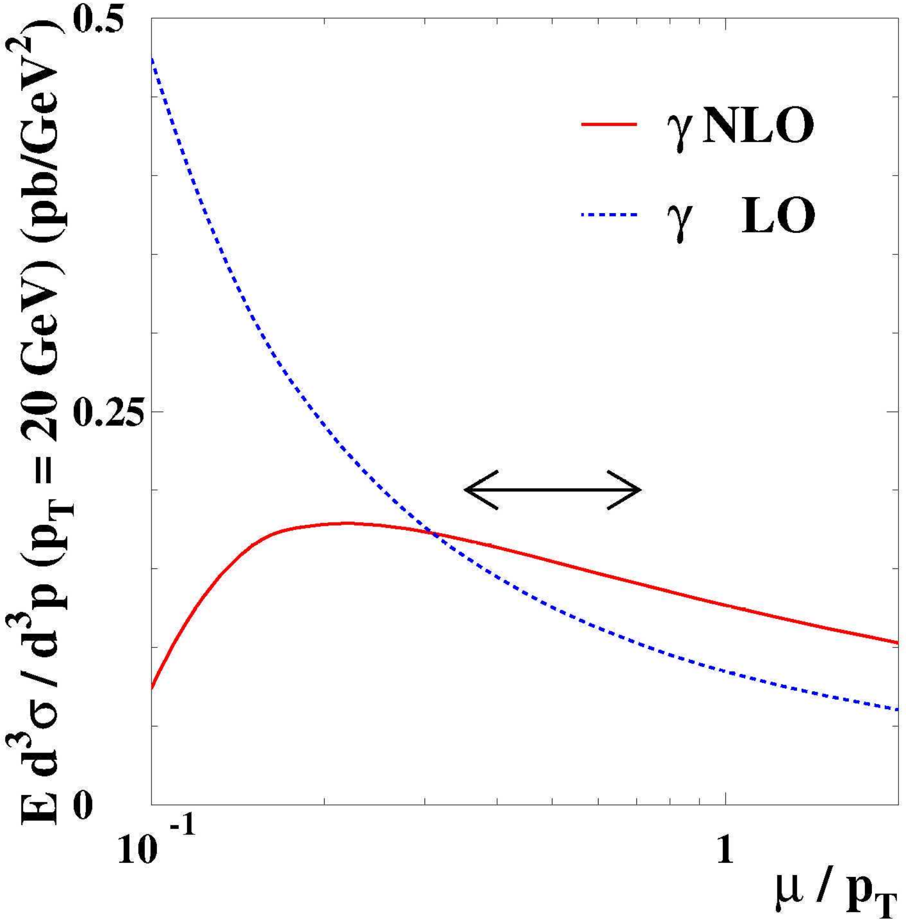


  - only the sum direct + fragmentation is meaningful and scale independent

Ingredients

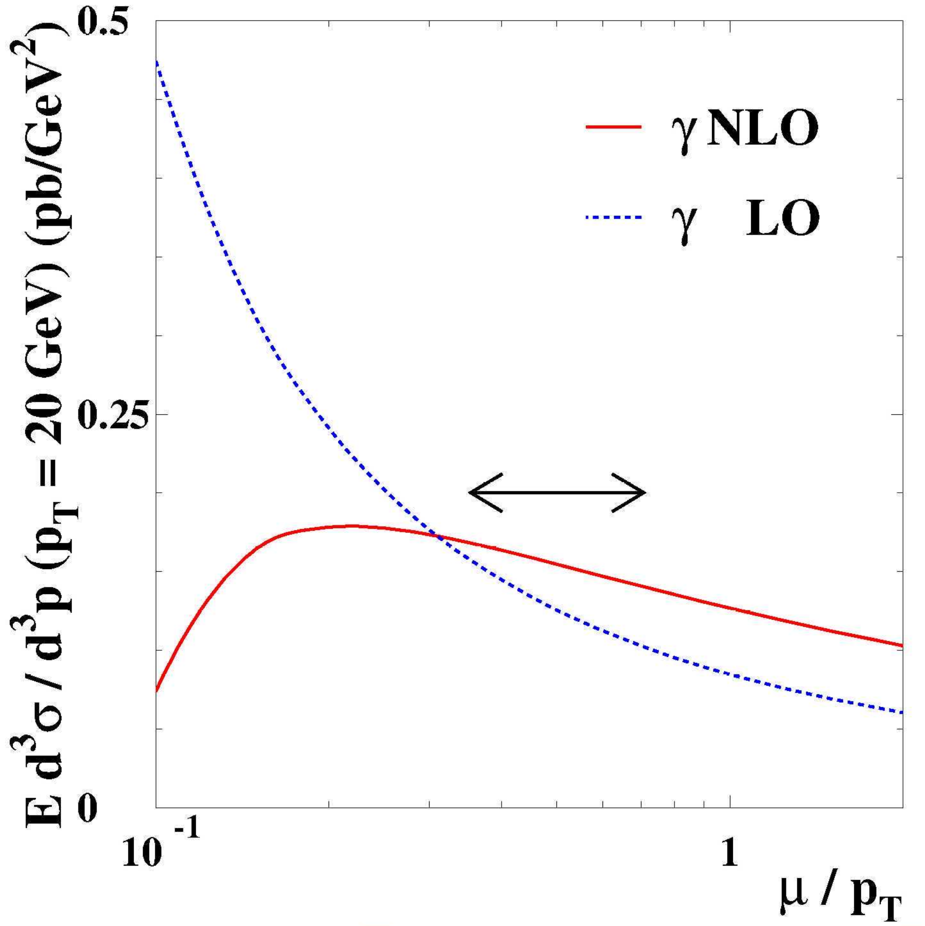
- $p\,p$ collisions
  - next-to-leading order
  - CTEQ6 parton densities
  - KKP (π^0) and BFG (γ) fragmentation functions
  - uncertainty given by the scale dependence

Scale dependence



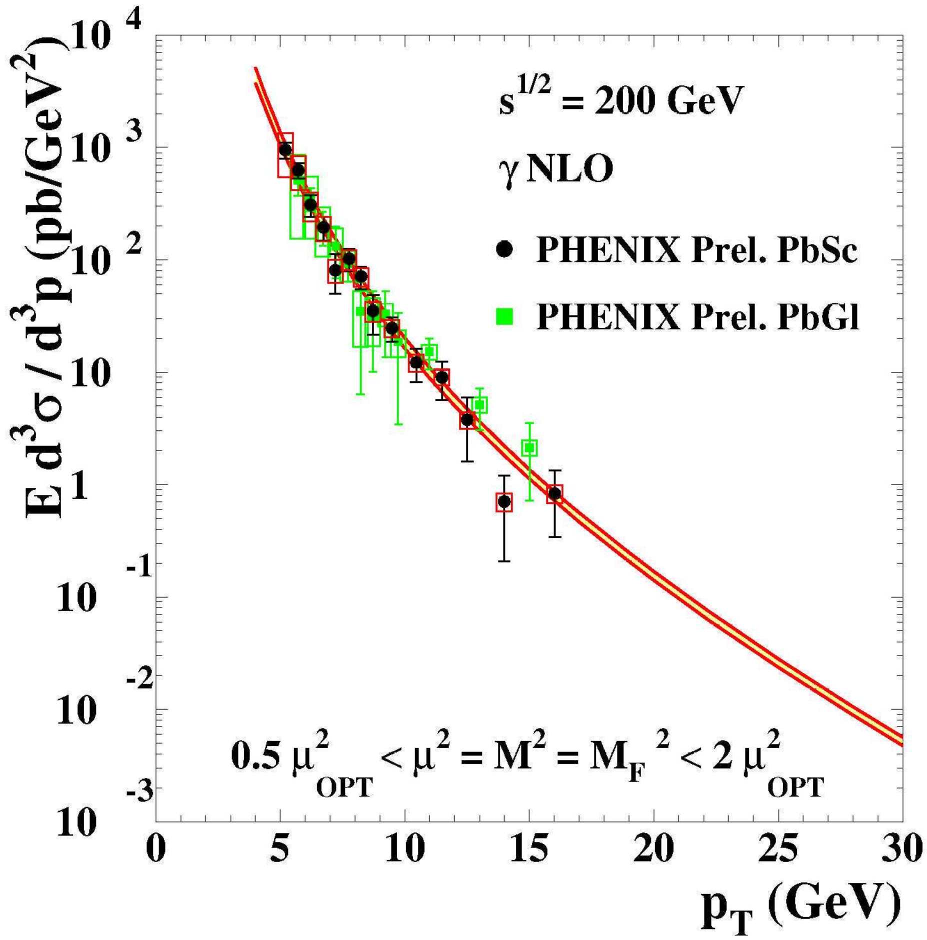
- Somehow stable at NLO
  - optimal scale $\mu_{\rm opt} \simeq p_\perp/2$

Scale dependence



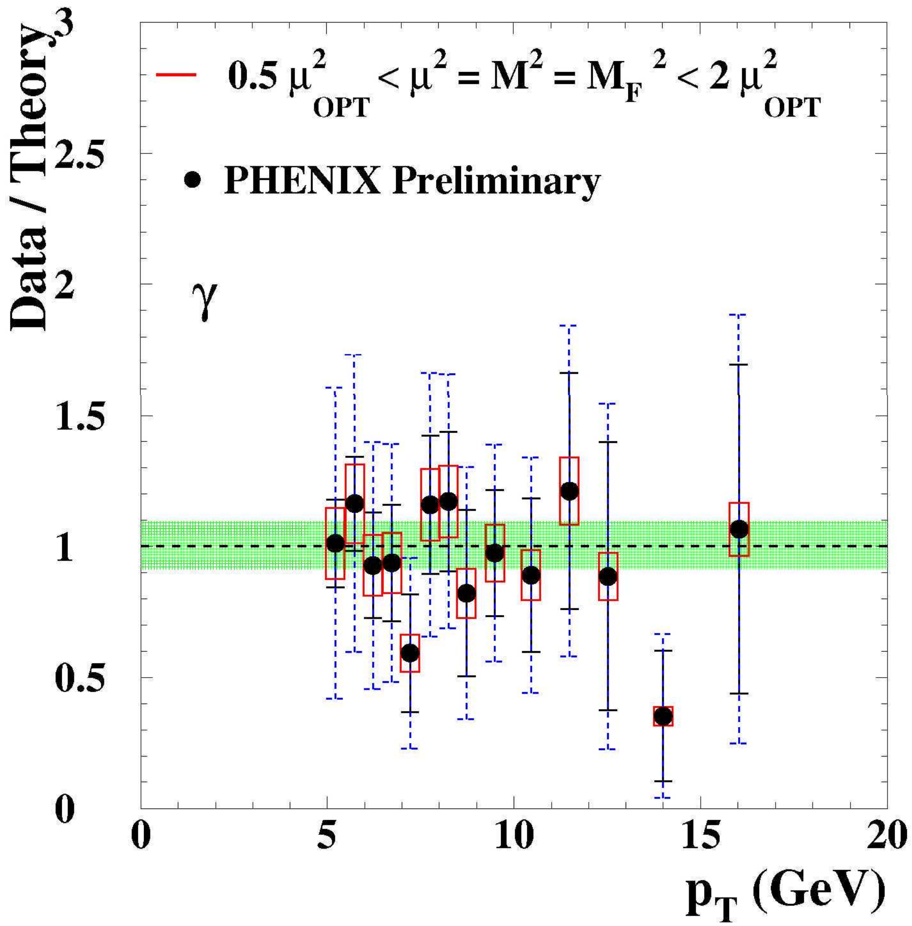
- Scales vary in the $\mu_{\rm opt}/\sqrt{2} \leq \mu = M = M_F \leq \sqrt{2}\,\mu_{\rm opt}$ range

Spectrum



- Good agreement with PHENIX data
  - constraints on fragmentation functions

Data over theory



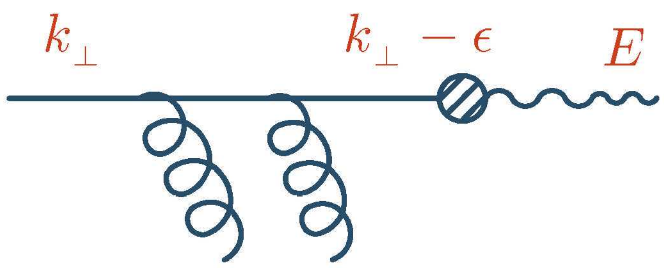
- Error dominated by the too low statistics
  - better data coming soon to probe theory ?

Ingredients

- A A collisions
  - leading order
  - only yield ratios A A / $p\ p$
  - with/out EKS98 shadowing
  - with/out energy loss

Model

Multiple scattering shifts parton energy from $k_\perp$ to $k_\perp - \epsilon$



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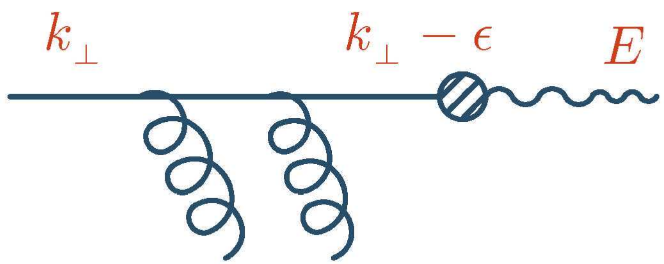

Simple model for medium-modified fragmentation functions

[Wang, Huang, Sarcevic 1996]

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

$$\text{with} \;\; z^* = \frac{E}{k_\perp - \epsilon} = \frac{z}{1 - \epsilon/k_\perp}$$

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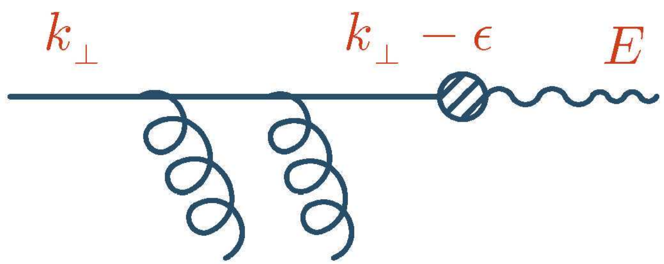

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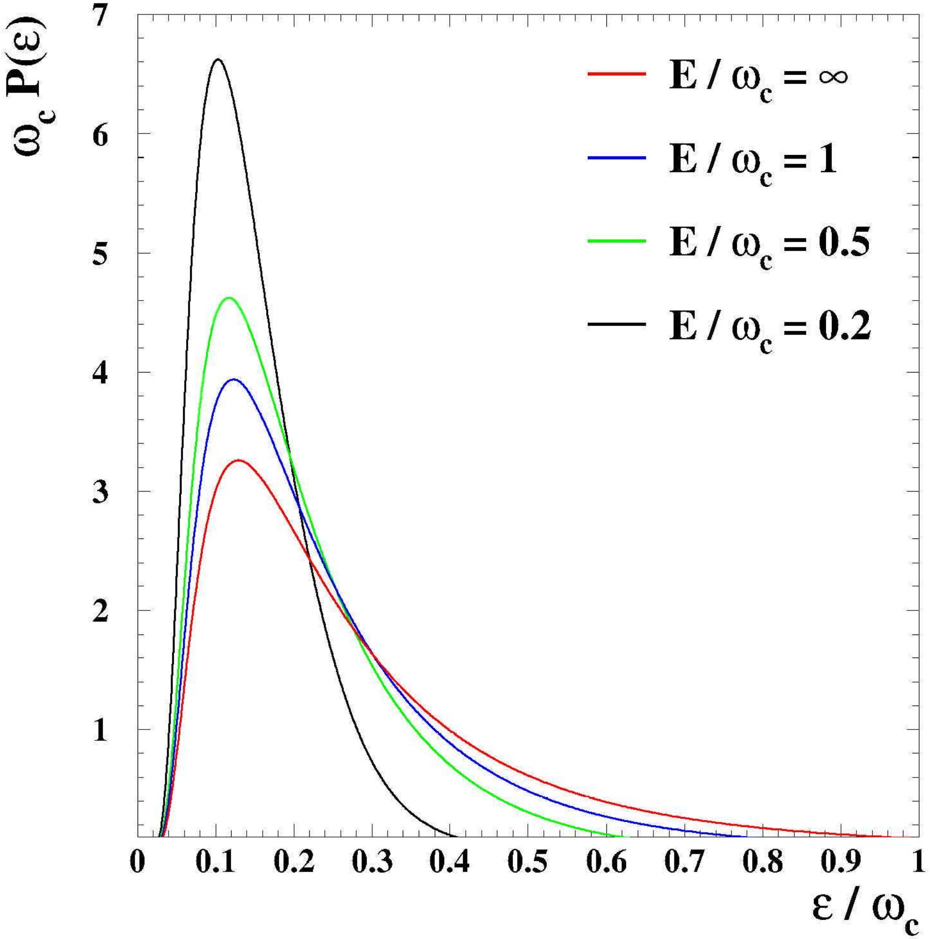
Probability distribution

[Baier, Dokshitzer, Mueller, Schiff JHEP 2001]
[FA JHEP 2002]

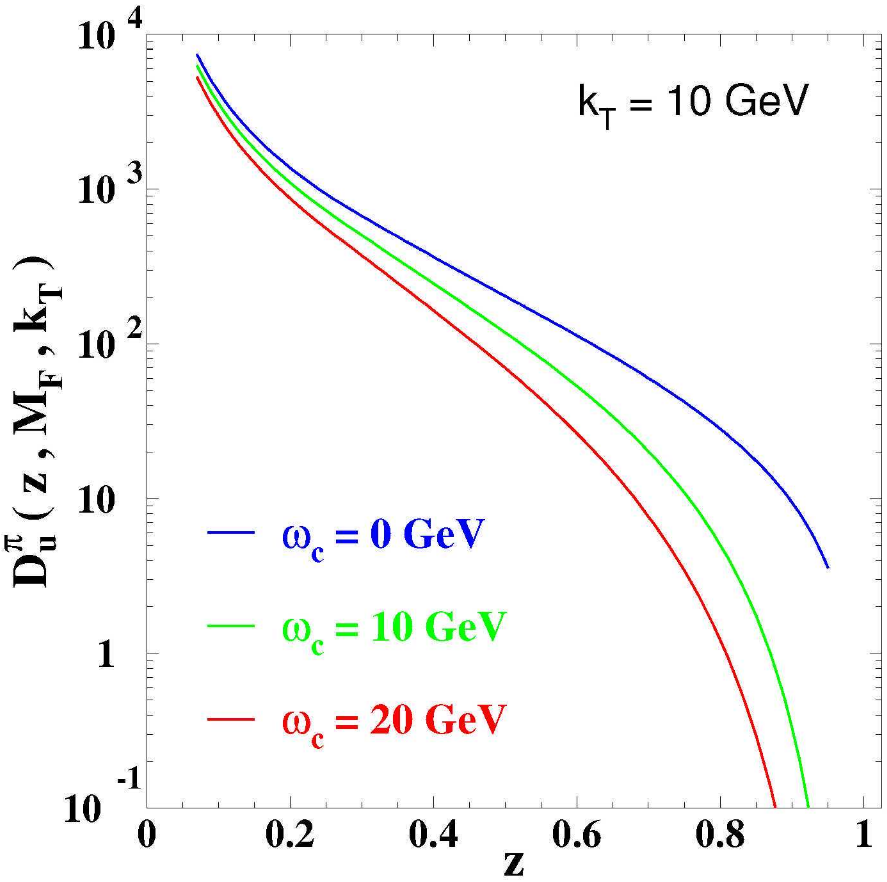


Scale

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

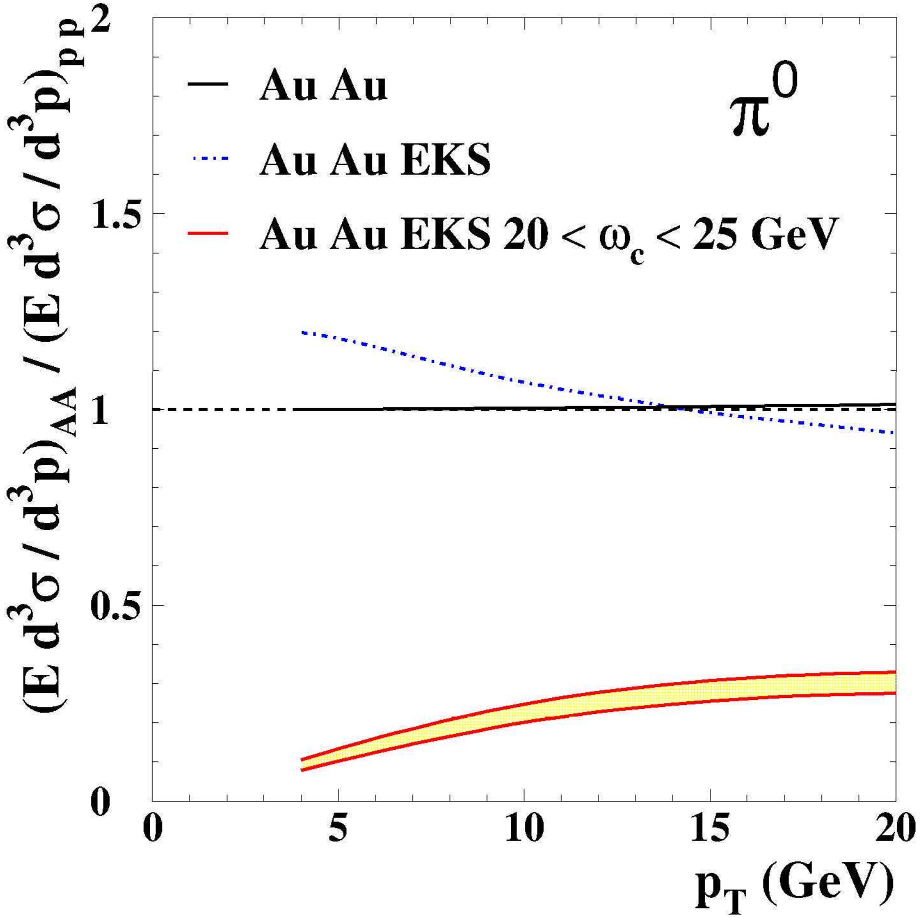
- $\hat{q}$: transport coeff.
  - diffusion μ^2/λ
- L : length

Medium-modified fragmentation functions



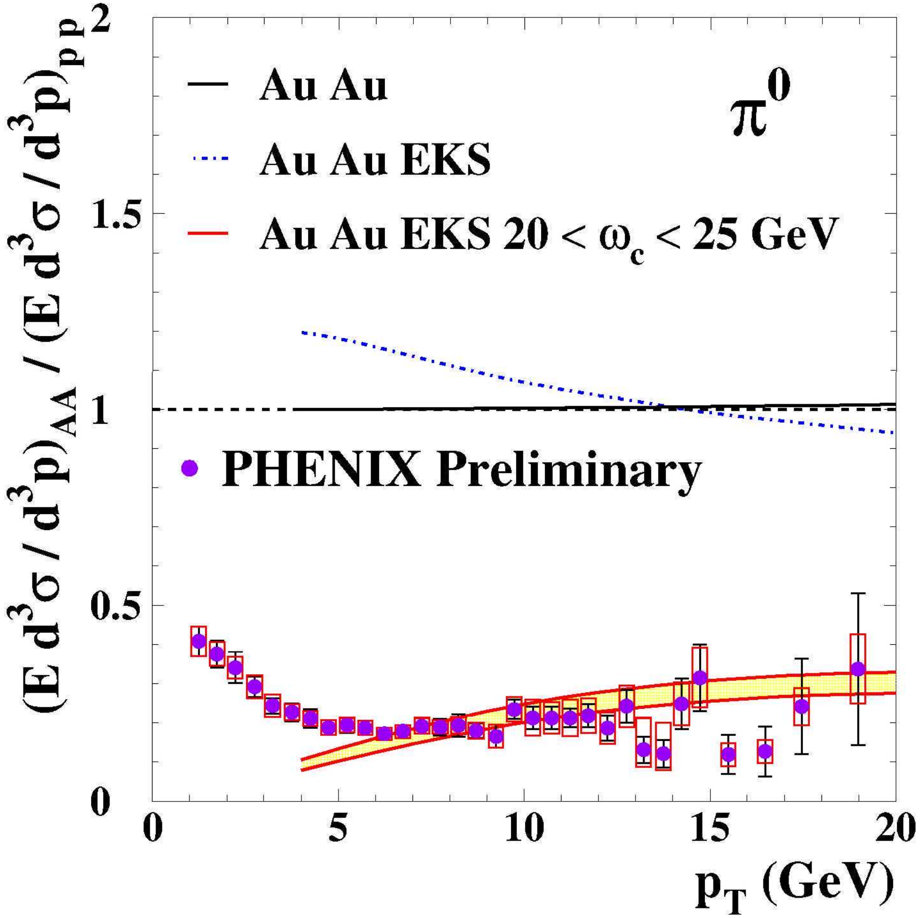
- Strong suppression at large z
- Pronounced effects for partons $k_\perp \lesssim \omega_c$

π quenching



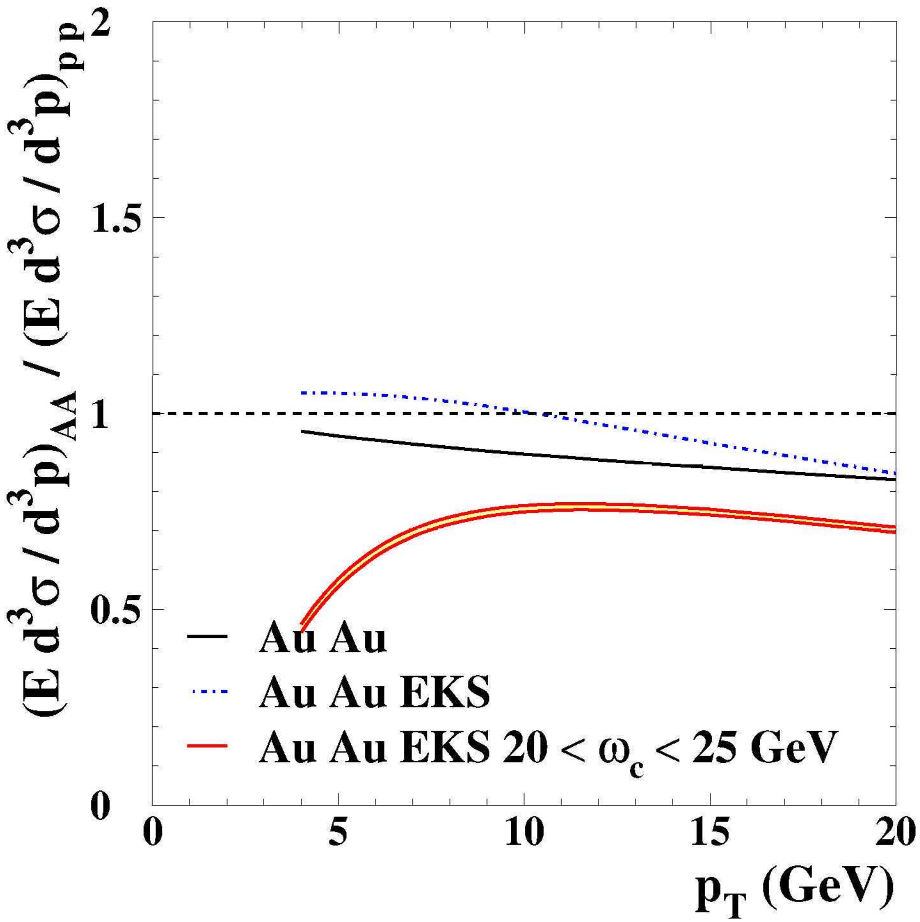
- Strong suppression in the π^0 channel

π quenching



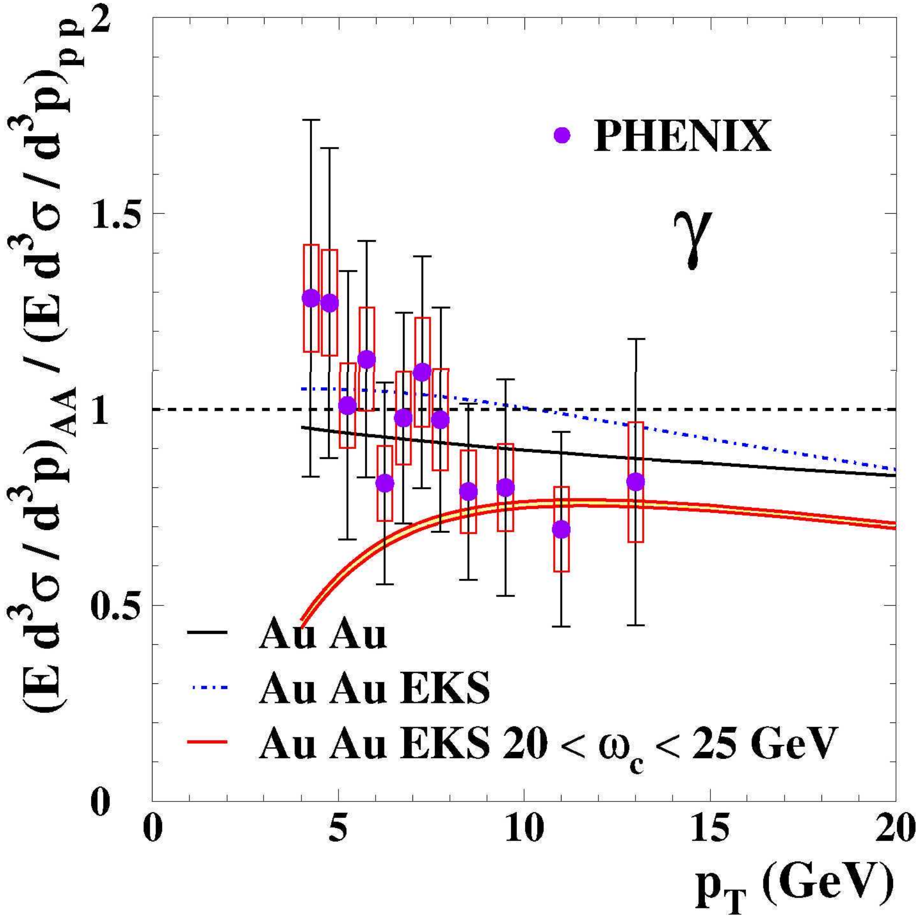
- Strong suppression in the π^0 channel
  - rather good agreement with data at large $p_\perp$
  - let's take $\omega_c \simeq 20 - 25$ GeV in the following

γ quenching



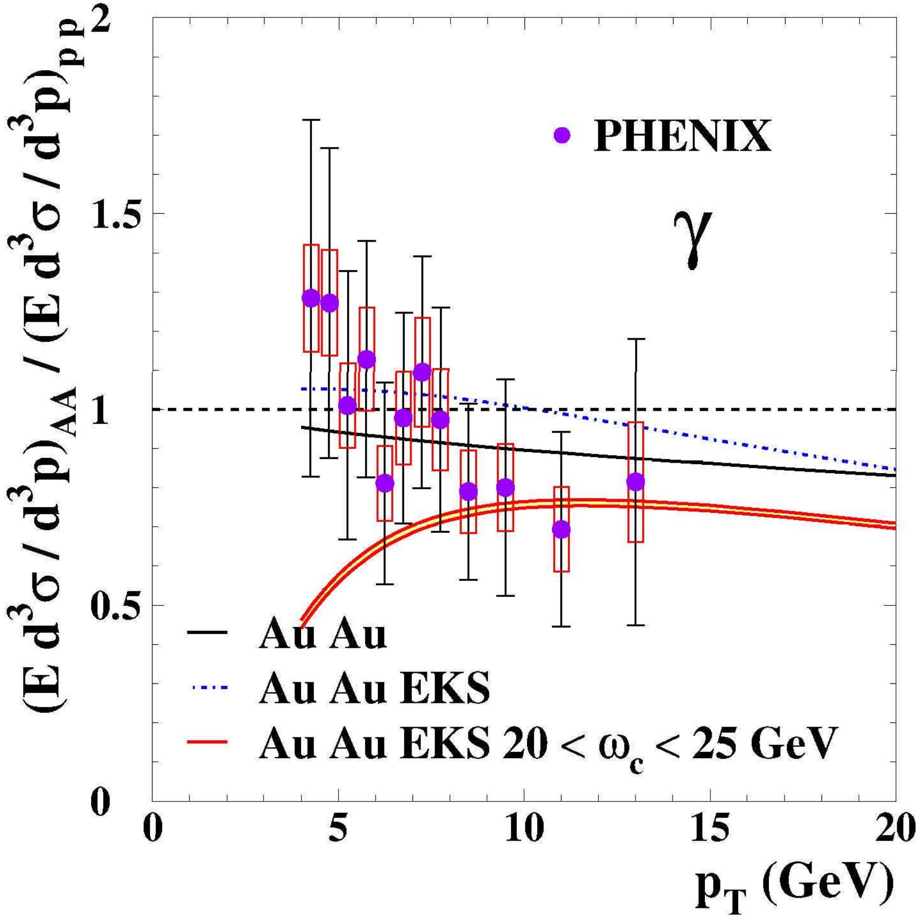
- Less quenched than π^0's
- Isospin effect not negligible !

γ quenching



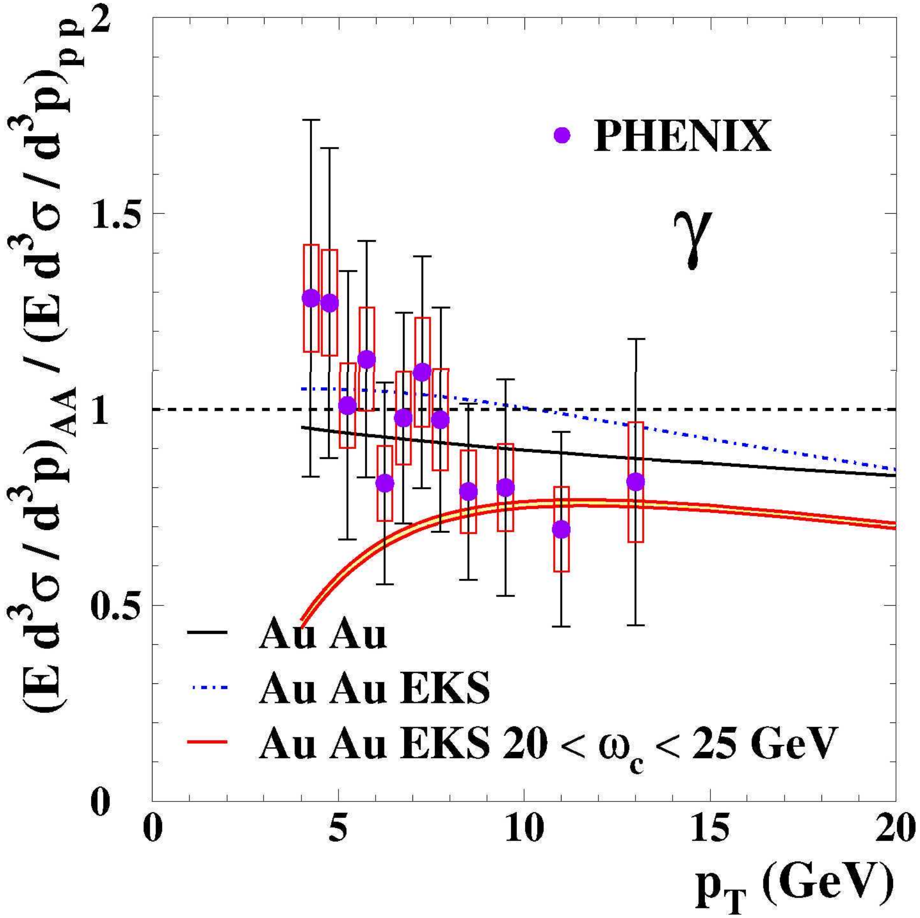
- Good agreement with PHENIX “data”, but . . .

γ quenching



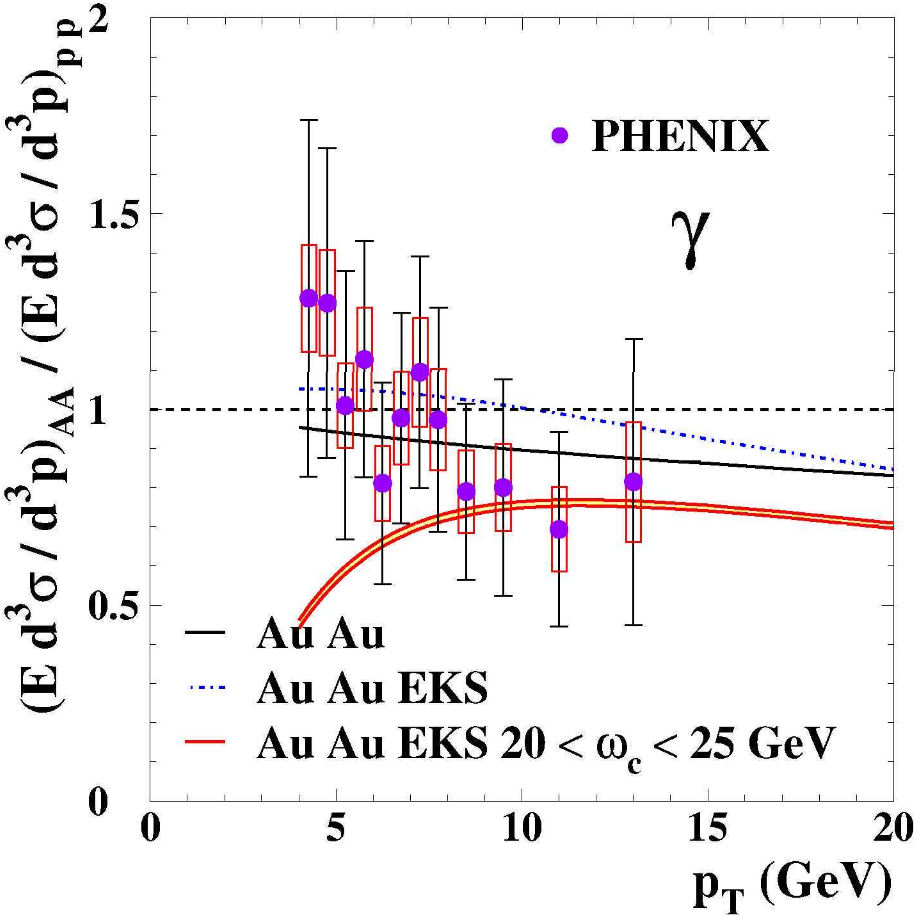
- Good agreement with PHENIX “data”, but . . .
- . . . these are “fake” data !

γ quenching



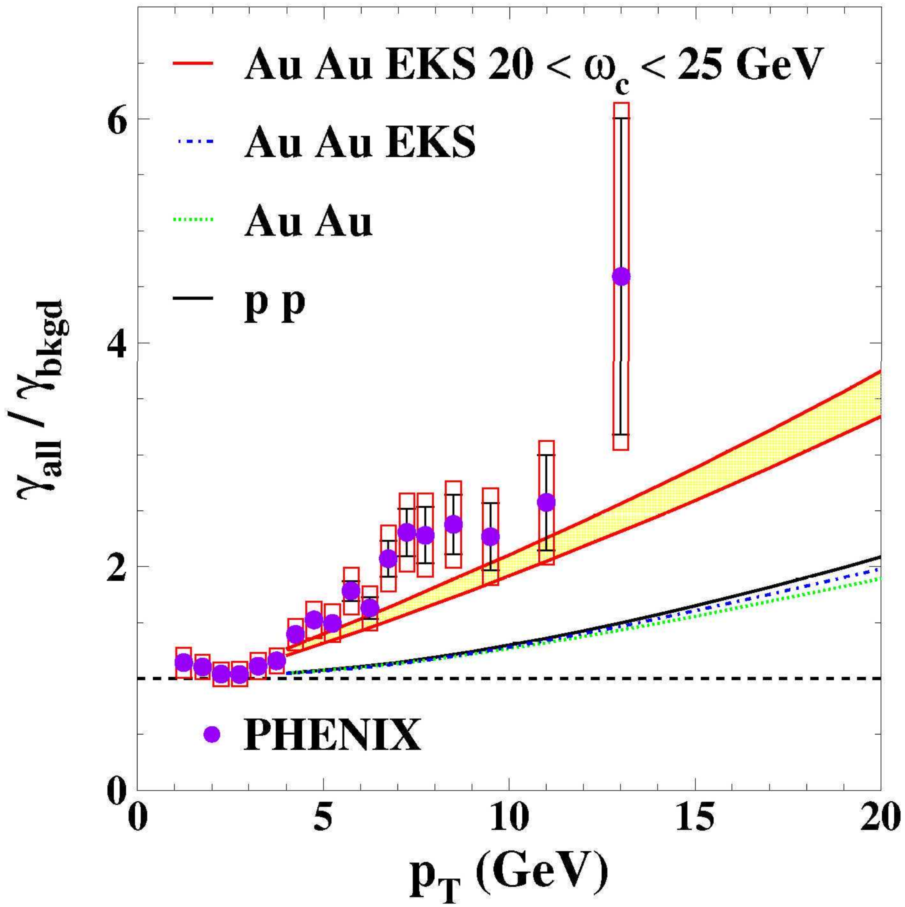
$$\text{real quenching} = \frac{\text{data A A}}{\text{data } p\,p}$$

γ quenching



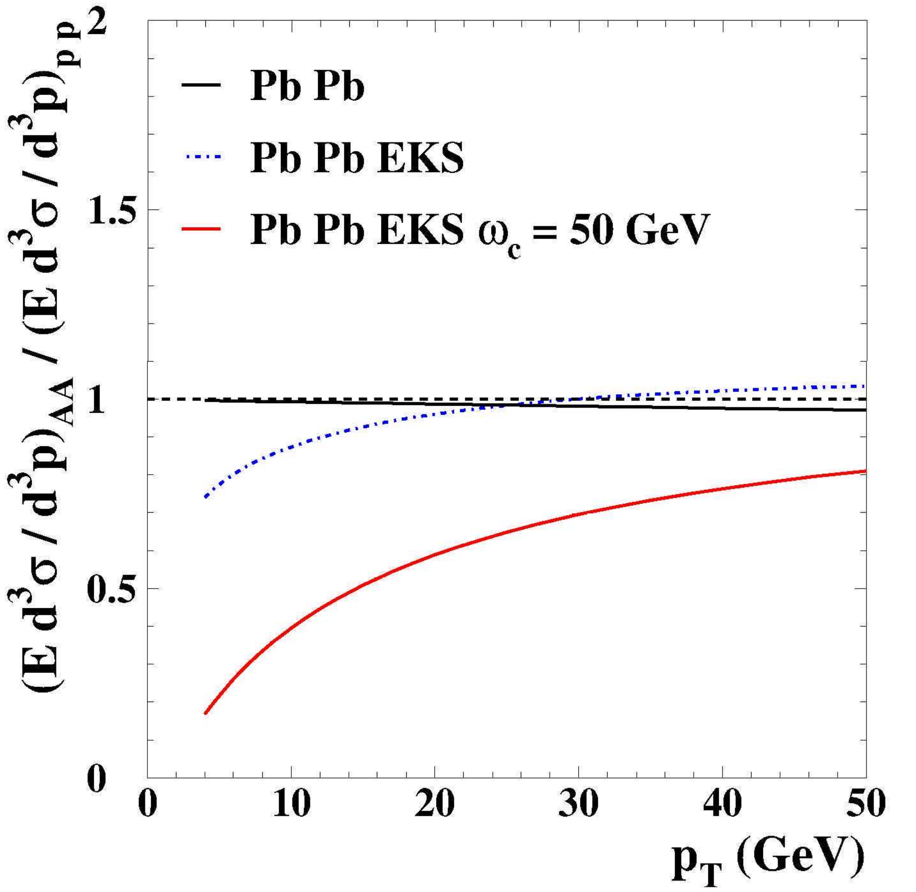
$$\text{fake quenching} = \frac{\text{data } A\ A}{\text{theory } p\ p}$$

γ / π



- slight underestimate at large $p_\perp$

γ quenching at LHC



- Shadowing corrections below $p_\perp \lesssim 20$ GeV
- Pronounced energy loss effects

Limits

Parton energy not fixed

Single inclusive spectra in pQCD to leading-order

$$\frac{\mathrm{d}\sigma^{\pi}}{\mathrm{d}\,\mathbf{p}_{\perp}\,\mathrm{d}y} = \sum_{i,j,k=q,g} \int dx_1 dx_2 F_{i/p}(x_1, M) F_{j/p}(x_2, M) \times \left(\frac{\alpha_s(\mu)}{2\pi}\right)^2 \frac{\mathrm{d}\widehat{\sigma}_{ij}k}{\mathrm{d}\,\mathbf{p}_{\perp}\,\mathrm{d}y} \frac{dz}{z^2} D_{\pi/k}(z, M_F)$$

do not allow one to determine

- parton energy $k_{\perp}$ thus the variable $z = p_{\perp_{\pi}} / k_{\perp}$
- medium-modified fragmentation functions

Limits

Parton energy not fixed

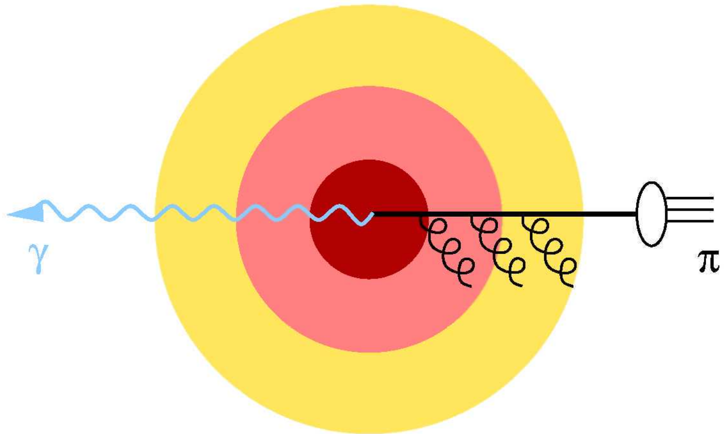
Need to go beyond single-inclusive production to better understand the medium-modified fragmentation processes

prompt photon — hard pion correlations

- momentum correlations
- azimuthal correlations

Correlations

- To leading-order in α_s



$$\mathbf{k}_\perp \simeq -\mathbf{p}_{\perp\gamma}$$

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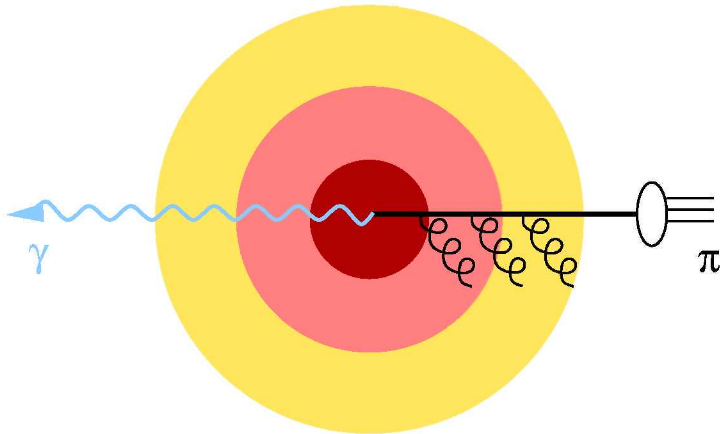


$$\mathbf{k}_\perp \simeq -\mathbf{p}_{\perp_\gamma}$$

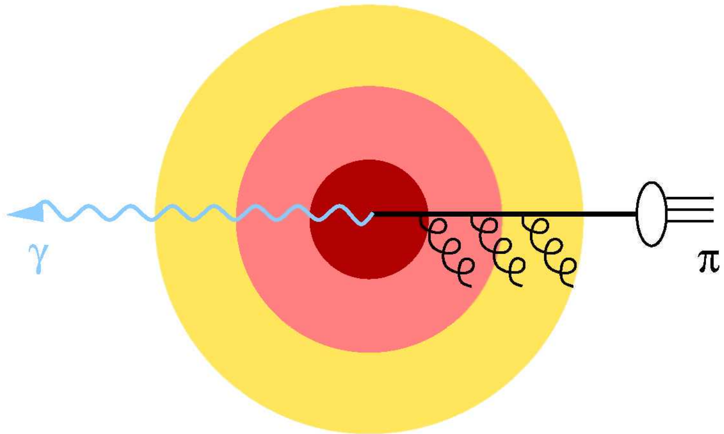
- Imbalance momentum

$$z_{\gamma\pi} \equiv -\frac{\mathbf{p}_{\perp_\pi} \cdot \mathbf{p}_{\perp_\gamma}}{|\mathbf{p}_{\perp_\gamma}|^2} \simeq z$$

allows for the estimate of the fragmentation variable z

Correlations

- To leading-order in α_s



$$\mathbf{k}_\perp \simeq -\mathbf{p}_{\perp\gamma}$$

perturbative calculation of correlation distributions

in $p\,p$ et A A collisions at RHIC

Kinematic cuts

Constraints

- Wide range in the $z_{\gamma\pi}$ variable
  - asymmetric cuts: $p_{\perp\pi}^{\mathrm{cut}} \ll p_{\perp\gamma}^{\mathrm{cut}}$

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$$\Lambda_{\rm QCD} \ll p_{\perp\pi}^{\rm cut} \ll p_{\perp\gamma}^{\rm cut} \ll \sqrt{s}\,/2$$

RHIC

$$p_{\perp\pi}^{\rm cut} = 3 \text{ GeV} \qquad p_{\perp\gamma}^{\rm cut} = 10 \text{ GeV}$$

Kinematic cuts

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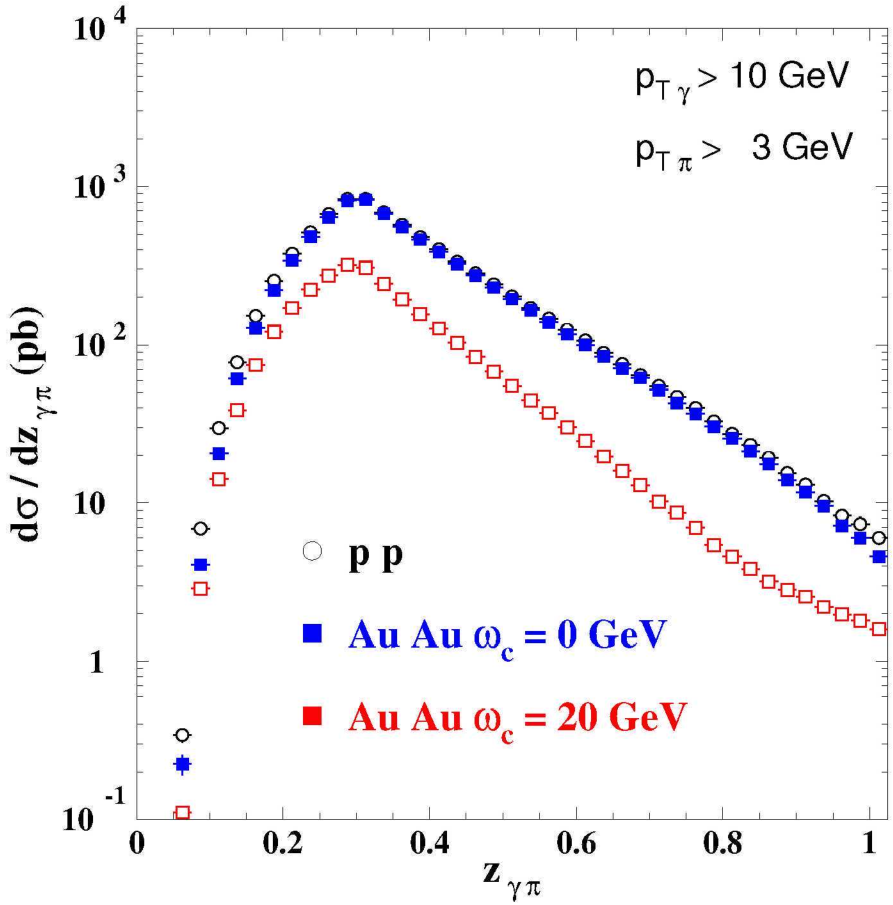
  - $p_{\perp\pi}^{\rm cut} \gg \Lambda_{\rm QCD}$

$$\Lambda_{\rm QCD} \ll p_{\perp\pi}^{\rm cut} \ll p_{\perp\gamma}^{\rm cut} \ll \sqrt{s}/2$$

LHC

$$p_{\perp\pi}^{\rm cut} = 5 \text{ GeV} \qquad p_{\perp\gamma}^{\rm cut} = 25 \text{ GeV}$$

Probing fragmentation



- Pronounced effects at large z
- Reflects fragmentation functions

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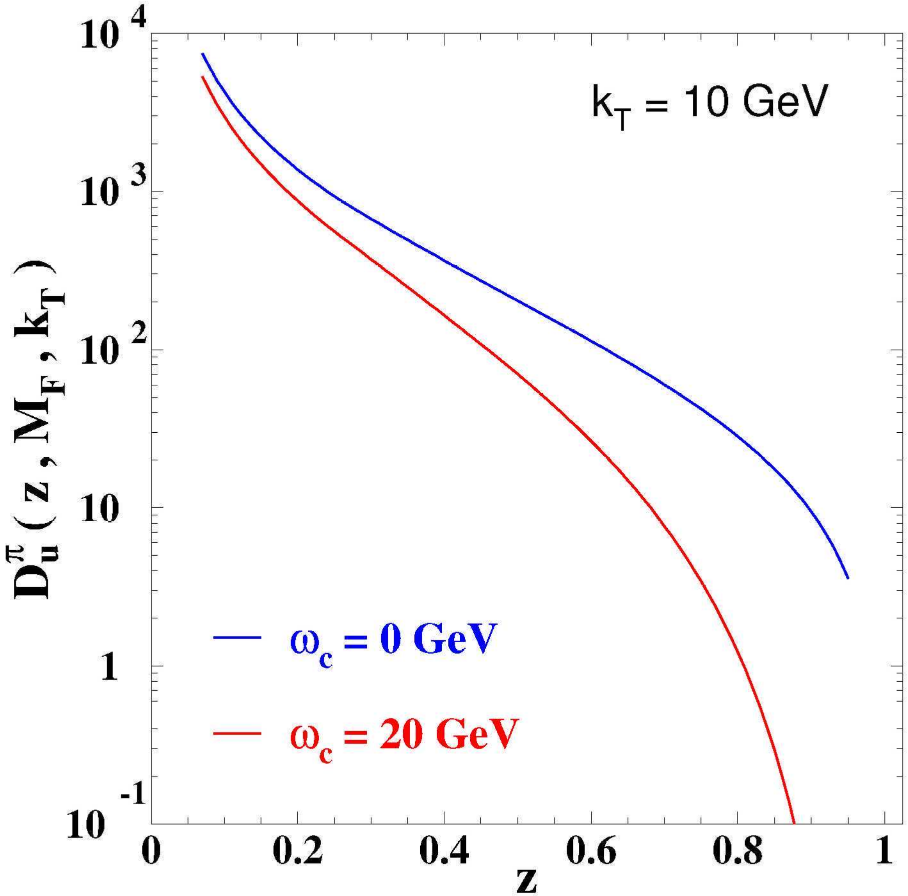

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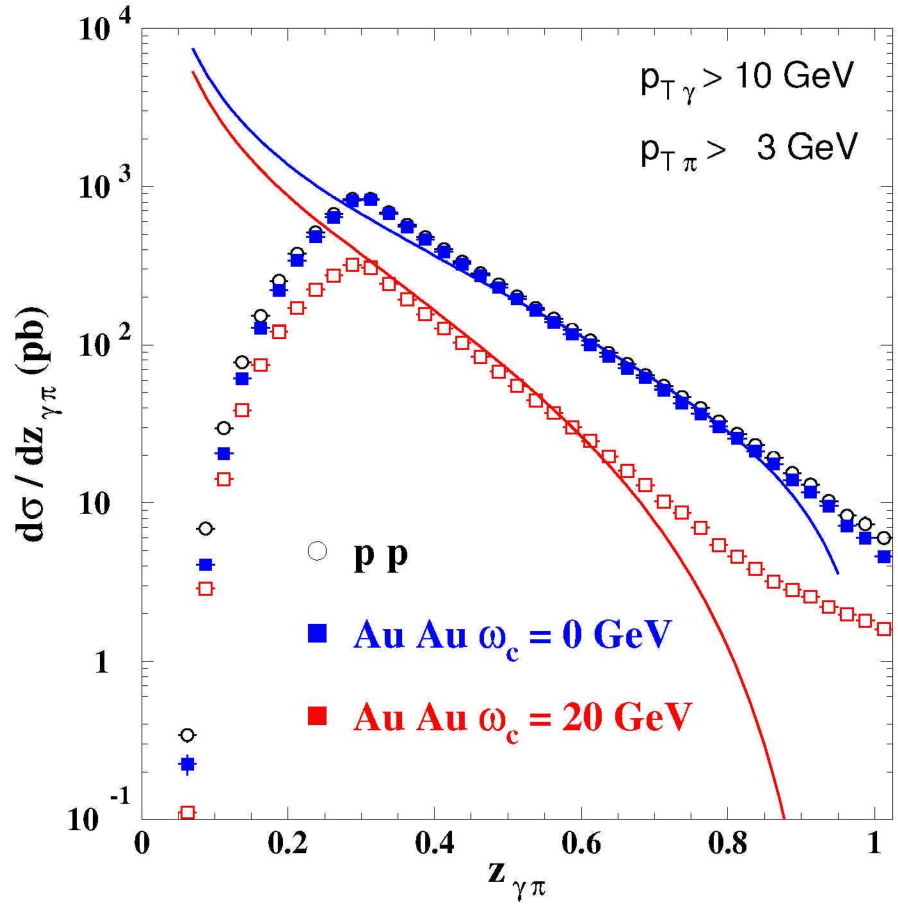
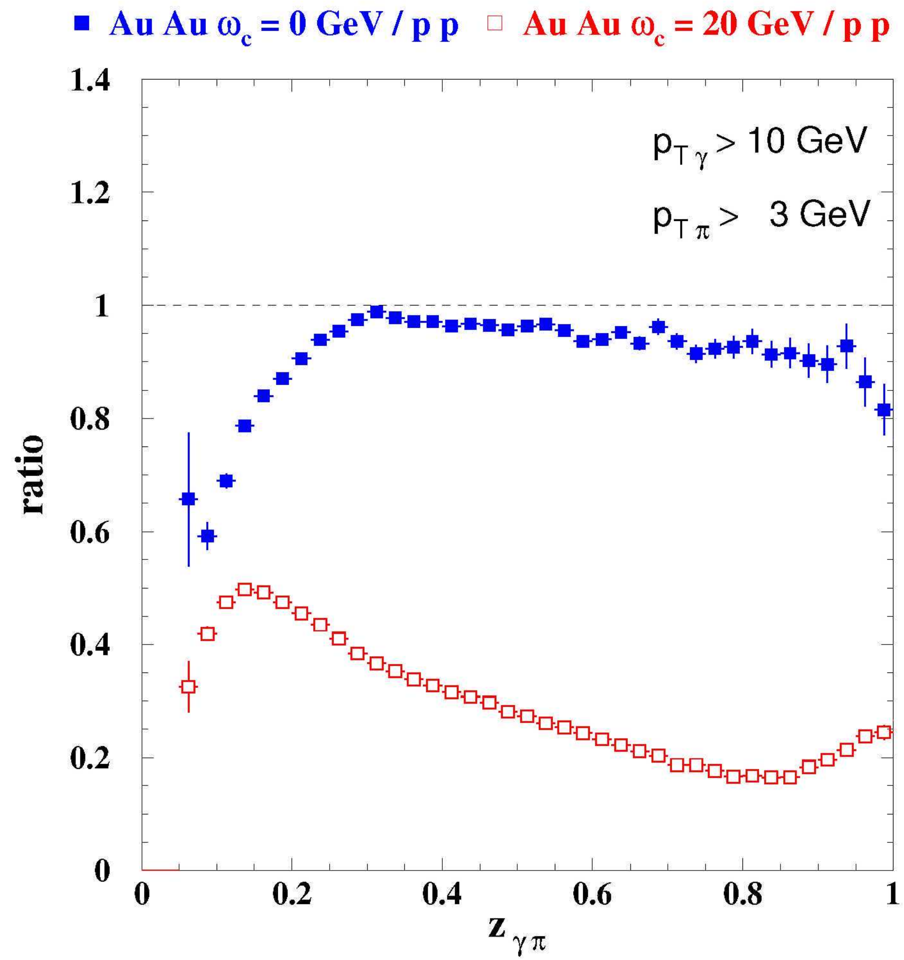


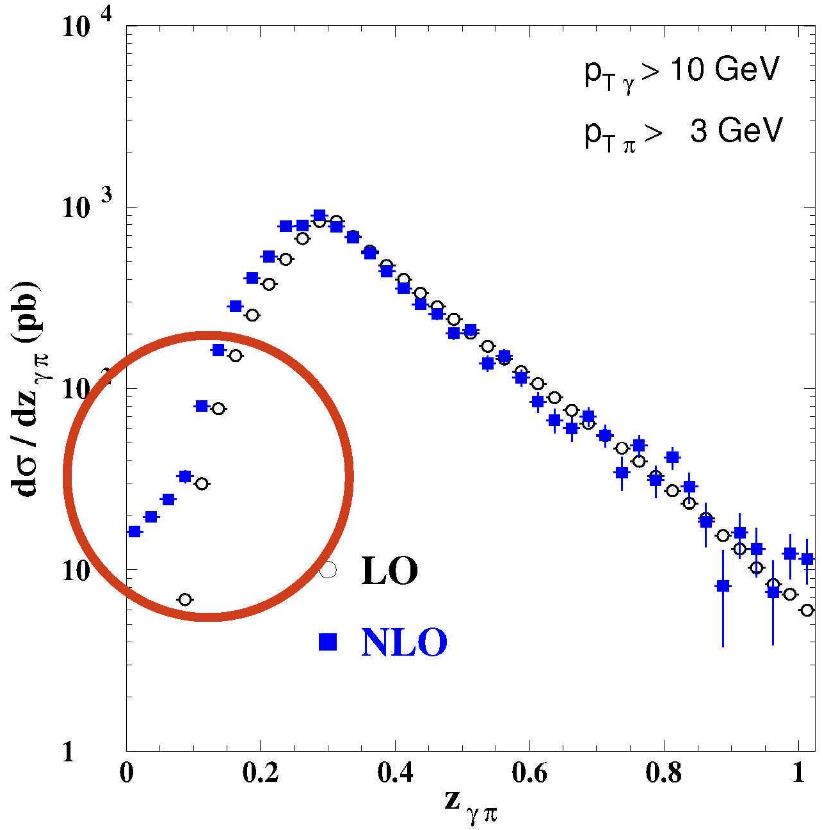
- The more asymmetric cuts the better
- Better to increase $p_{\perp\gamma}^{\mathrm{cut}}$ to reduce the double fragmentation

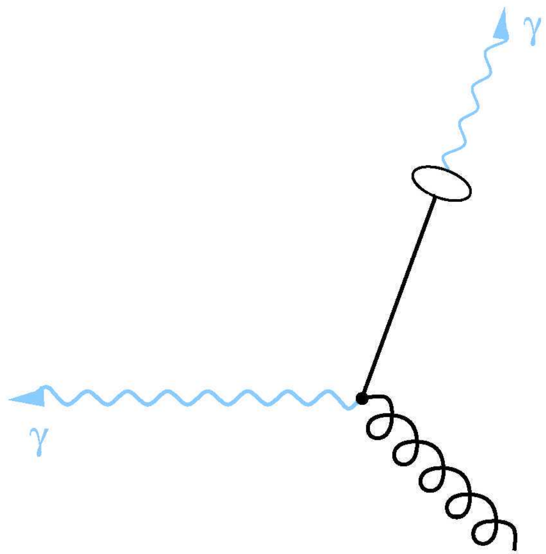
Probing fragmentation



- Significant effect at RHIC
- Energy loss and shadowing quite different

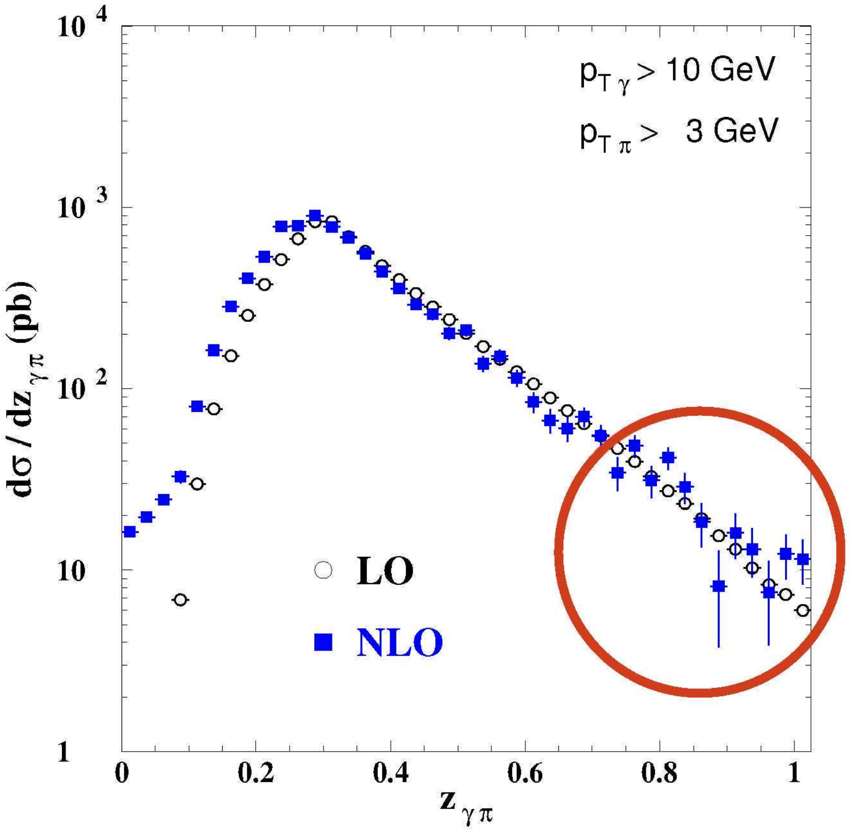
Higher-order corrections

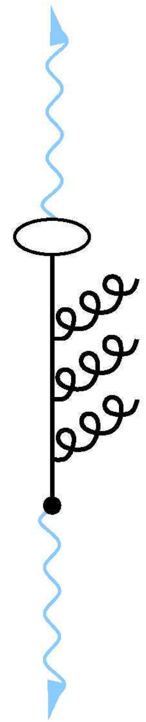




- New configurations in momentum space

Higher-order corrections

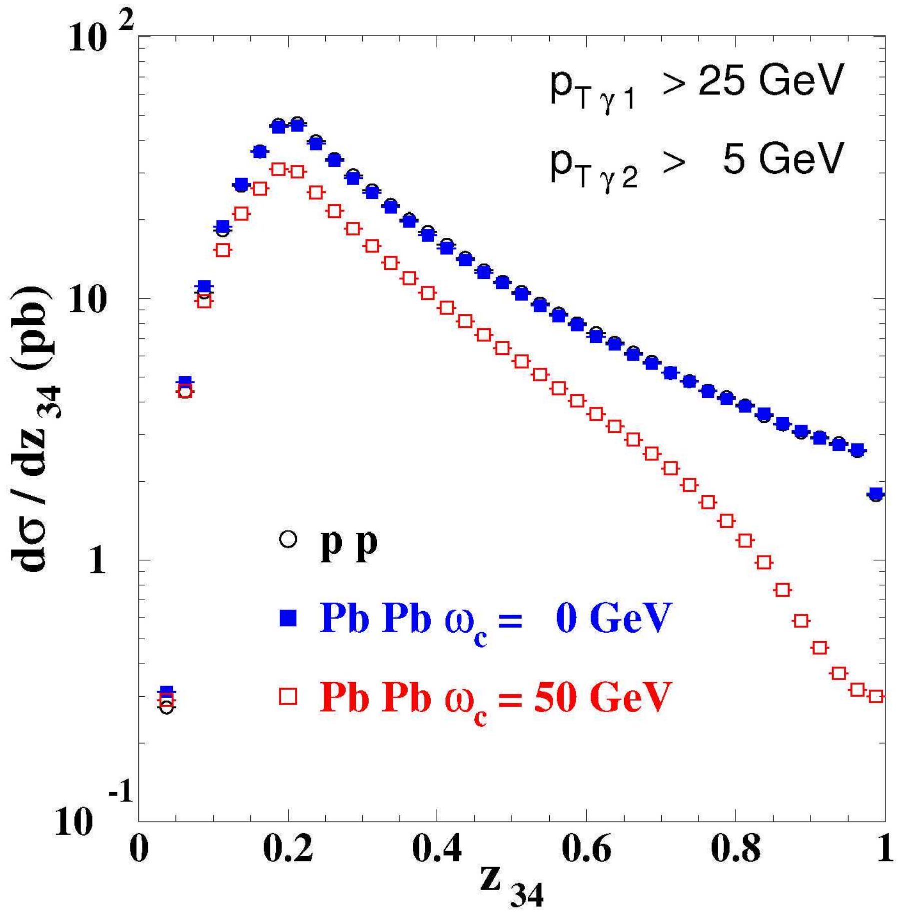




- New configurations in momentum space
- Infrared sensitivity at $z_{\gamma\pi} \lesssim 1$

Diphoton at LHC

[FA, Aurenche, Belghobsi, Guillet 2004]



- One γ produced directly, one produced by fragmentation
- Allows for constraints on the rather unknown γ FF

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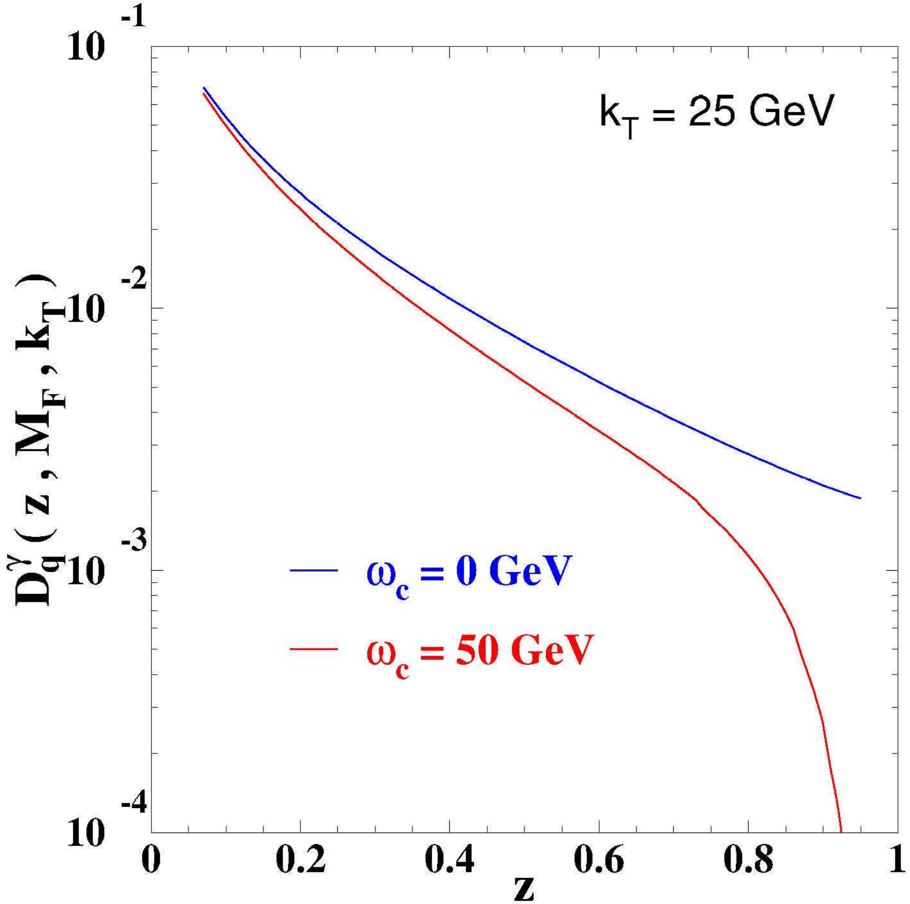

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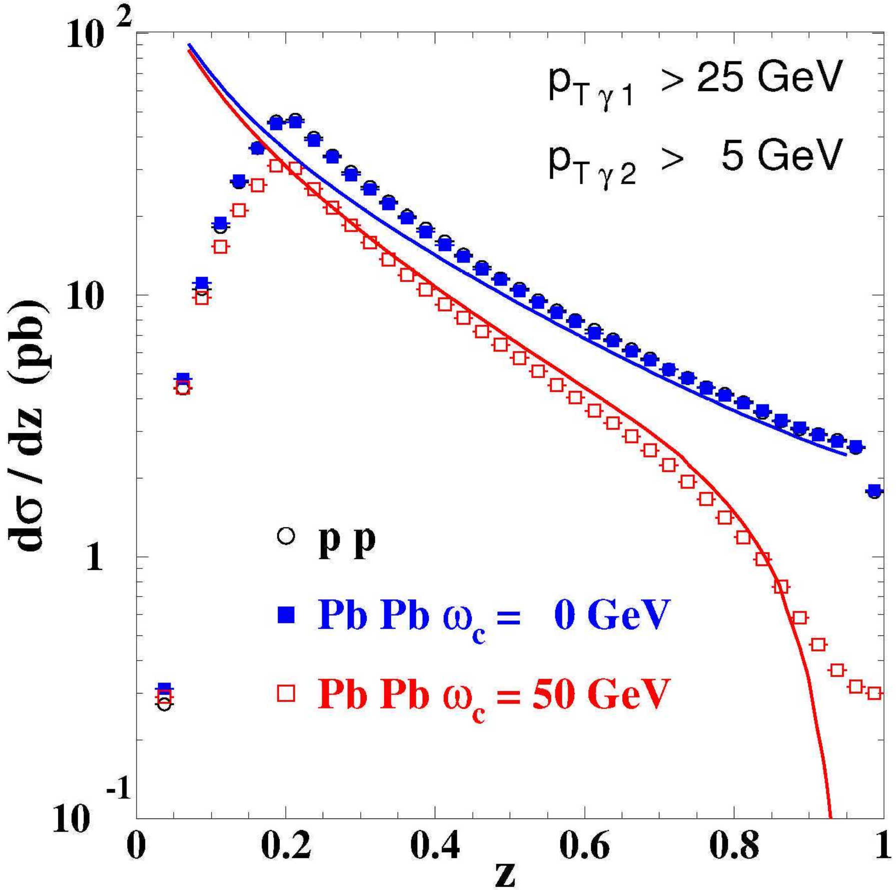

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Summary

- Single inclusive production
  - evidence for dense medium formation
  - slight quenching for photons in agreement with PHENIX
  - limitations

- Correlations $\gamma - \pi^0$
  - hopefully efficient to probe fragmentation processes
  - phenomenology at RHIC and LHC