Prompt photon production at LHC: a “multi-purpose” observable

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Last Call for Predictions

May-June 2007 – CERN

Outline

- Single photon in p A collisions
  - probing gluon shadowing with isolated photons
- Single photon in A A collisions
  - probing energy loss with inclusive photons
- Double photon and pion in A A collisions
  - probing medium-modified fragmentation functions

[FA, Gousset, in preparation]
[FA, JHEP 09 (2006) 015]
[FA, Aurenche, Belghobsi, Guillet, JHEP 11 (2004) 009]

Isolated photons in p A collisions:

measuring gluon shadowing

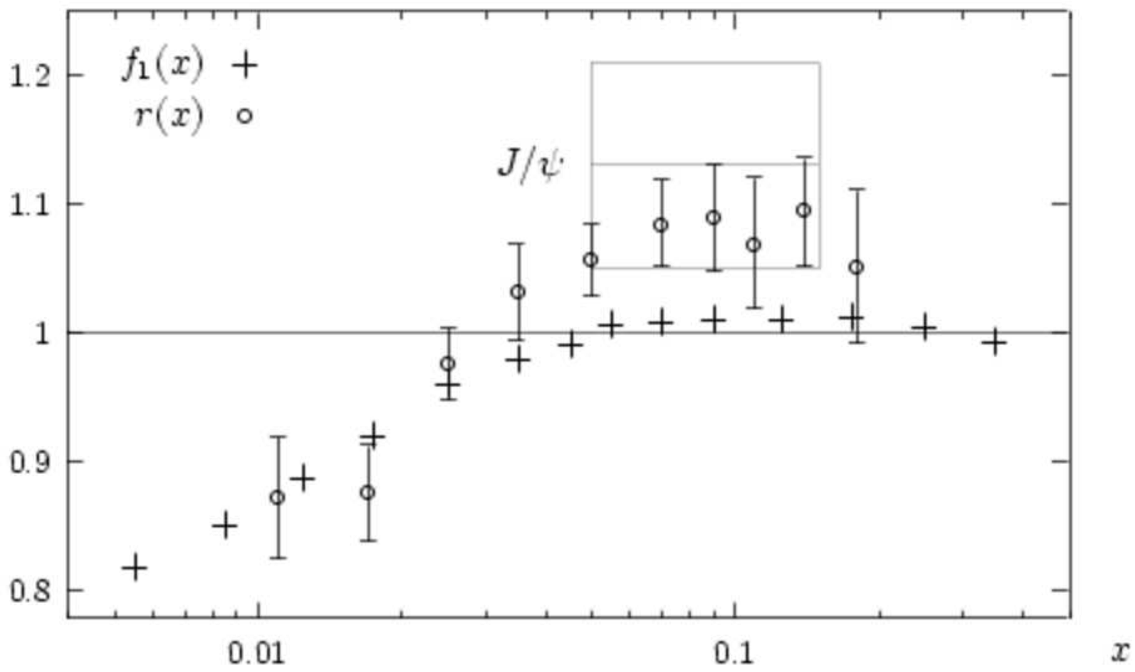
Gluon distributions in nuclei over that in a proton

$$R_G(x, Q^2) = G_A(x, Q^2)/G_p(x, Q^2)$$

poorly constrained experimentally!

Gluon shadowing

From NMC data



[Gousset, Pirner 1996]

- Tiny constraints from the scaling violation of $F_2^{A}(x, Q^2)$
- Fairly large $x \sim 10^{-2}$–10^{-1}

Gluon shadowing

Gluon distributions in nuclei over that in a proton

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How to probe small-x gluon shadowing at LHC ?

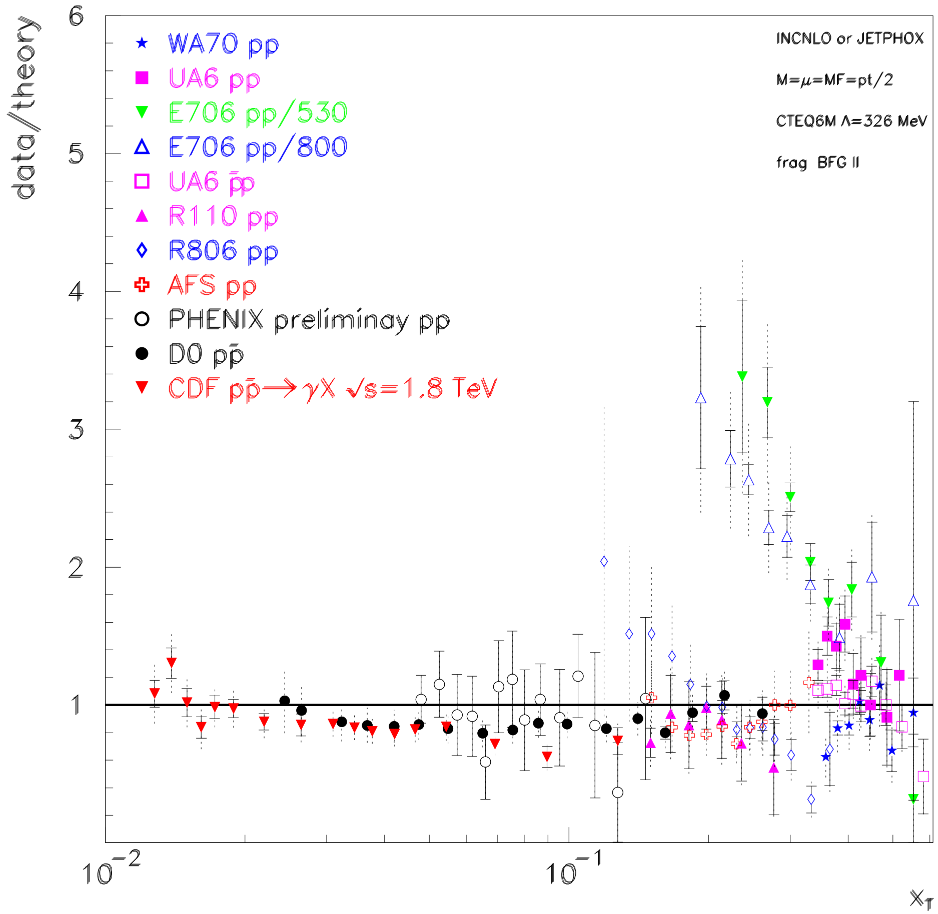
- which observables
- why prompt photons

Observables

Choose your favourite one !

- **Jets**
  - :-) high rates, rich phenomenology, forward rapidities
  - :-(large scales $Q^2 \gtrsim 10^3$ GeV^2
- **Large $p_\perp$ dileptons**
  - :-) no strong background
  - :-(very low rates
- **Heavy-bosons**
  - :-) constraints on sea-quark shadowing
  - :-(large scales $Q^2 \gtrsim 10^4$ GeV^2
- **Prompt photons**
  - :-) low $Q^2 \gtrsim 10$–10^3 GeV^2, rich phenomenology
  - :-(parton-to-photon fragmentation process

Observables



[Aurenche et al. 2006]

- Good description of isolated/inclusive photon world-data

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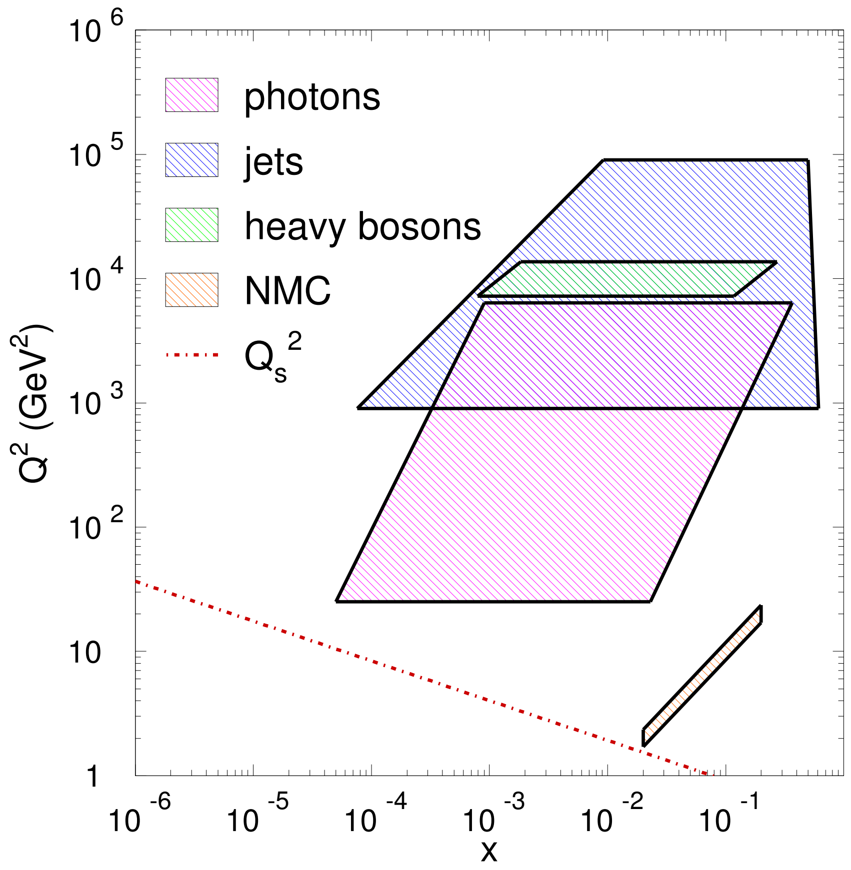
Kinematics

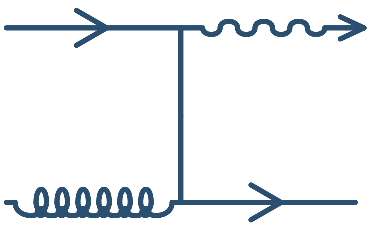


- Photons and jets are clearly complementary
- Photons cover small Q^2 where shadowing should be large

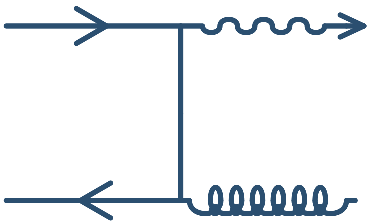
Photons in pQCD

At leading-order $\mathcal{O}\left(\alpha\ \alpha_s\right)$

- Compton scattering $q\ g \rightarrow q\ \gamma$



- Annihilation process $q\ \bar{q} \rightarrow g\ \gamma$



At high energy, only the Compton scattering process is relevant

Photons in pQCD

At leading-order $\mathcal{O}\left(\alpha\ \alpha_s\right)$

$$\frac{\mathrm{d}^3\sigma(p\,\mathrm{A}\to\gamma\,\mathrm{X})}{\mathrm{d}y\ \mathrm{d}^2p_\perp} \propto \int_0^1 \mathrm{d}v\ \tilde{F}_2^{\,p}\left(\frac{x_\perp e^{y}}{2v}\right) G^{\mathrm{A}}\left(\frac{x_\perp e^{-y}}{2(1-v)}\right) |\mathcal{M}|^2(v) + G^{p}\left(\frac{x_\perp e^{y}}{2v}\right) \tilde{F}_2^{\,\mathrm{A}}\left(\frac{x_\perp e^{-y}}{2(1-v)}\right) |\mathcal{M}|^2(1-v)$$

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Since $R_G(x)$ and $R_{F_2}(x)$ vary slowly wrt $G(x)$ and $F_2(x)$

$$R_{p\mathrm{A}}(p_\perp, y) \simeq c(y)\; R_{F_2}(x_\perp e^{-y}) + [1 - c(y)]\; R_G(x_\perp e^{-y})$$

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$$R_{p\mathrm{A}}(p_\perp,y) \simeq c(y)\,R_{F_2}(x_\perp e^{-y}) + [1-c(y)]\,R_G(x_\perp e^{-y})$$

but . . .

Caveat

Photons can also be produced by fragmentation

$$\frac{d^3\sigma^{\text{frag}}(p\,A \to \gamma\,X)}{dy\, d^2p_\perp} \propto \int_0^1 dz \int_0^1 dv\ \ldots (x_\perp/z, Q^2)\ D_{\gamma/k}(z, Q^2)$$

The extra integration spoils the relationship $R_{pA} \Leftrightarrow R_{F_2}$ and R_G

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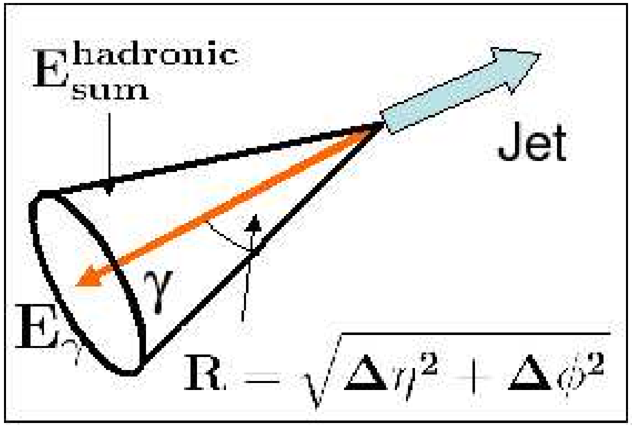
The extra integration spoils the relationship $R_{pA} \Leftrightarrow R_{F_2}$ and R_G

We get rid of them by means of isolation criteria

$$E_\perp^{\rm had} \leq E_\perp^{\rm max}$$

for particles in a cone

$$(\eta - \eta_\gamma)^2 + (\phi - \phi_\gamma)^2 \leq R^2$$



Predictions

Isolated photons in p A at LHC [FA, Gousset 2007]

- Around mid-rapidity

$$R_{pA}(p_\perp, y) \simeq \frac{1}{2}\left[R_{F_2}(x_\perp e^{-y}) + R_G(x_\perp e^{-y})\right]$$

- At (very) forward rapidity

$$R_{pA}(p_\perp, y) \simeq R_G(x_\perp e^{-y})$$

- At (very) backward rapidity

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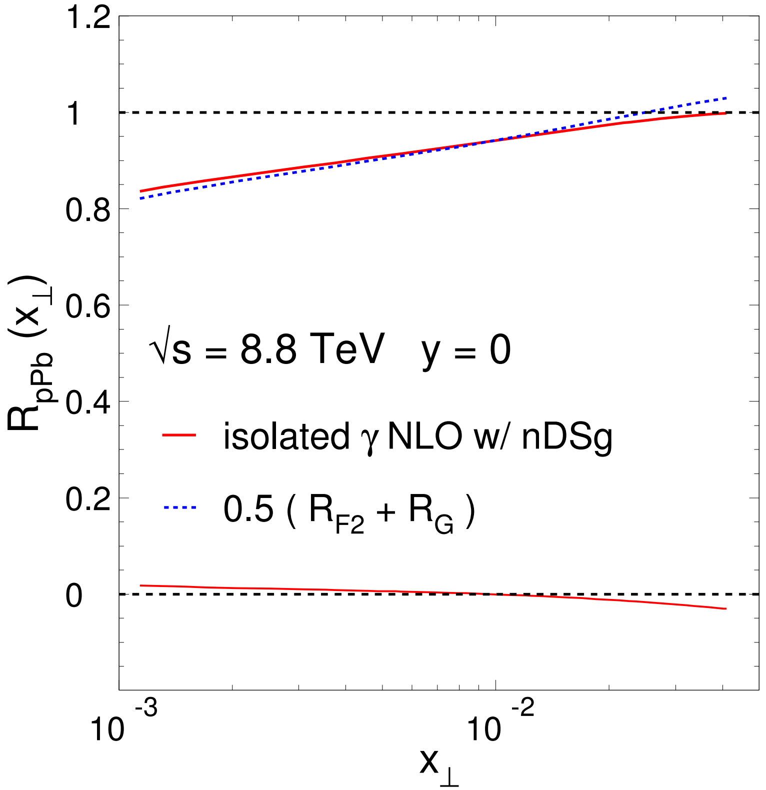
To illustrate/check this

let's compute $R_{pA}(x_\perp, y)$ at $y = 0, 2.5, -2.5$ at NLO using nDSg nuclear PDF in p A collisions ($\sqrt{s_{NN}} = 8.8$ TeV)

Predictions

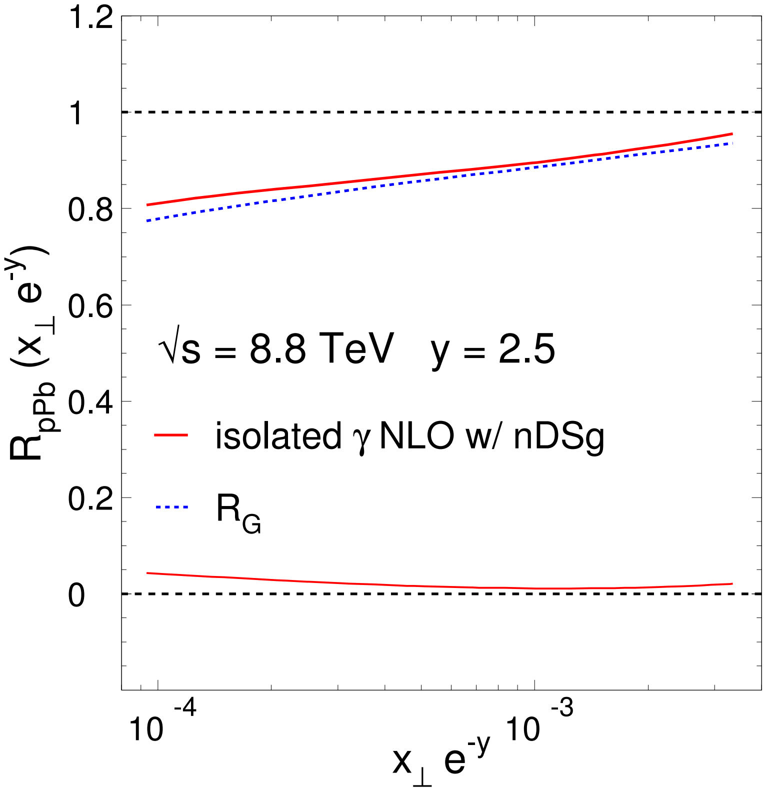
Mid-rapidity



- 20% attenuation at $x_\perp \sim 10^{-3}$ measurable (statistically)
- perfect ($< 2–3\%$) matching between R_{pA} and nuclear density ratios

Predictions

Forward rapidity $y = 2.5$



- Gives "direct" access to R_G (within 5%) at $x = 10^{-4}$–10^{-3} !

Shadowing without p p data

Problem: no p p collision at $\sqrt{s} = 8.8$ TeV

How to measure $R_G(x)$ without any p p reference data ?

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Compare forward w/ backward production in p A collisions

$$\frac{\mathrm{d}\sigma(p\ \mathrm{A} \rightarrow\ \gamma(+y)\ \mathrm{X}\,)}{\mathrm{d}\sigma(p\ \mathrm{A} \rightarrow\ \gamma(-y)\ \mathrm{X}\,)} = R_{p\mathrm{A}}(x_\perp, +y)/R_{p\mathrm{A}}(x_\perp, -y)$$

$$\simeq R_G(x_\perp e^{-y})/R_{F_2}(x_\perp e^{y})$$

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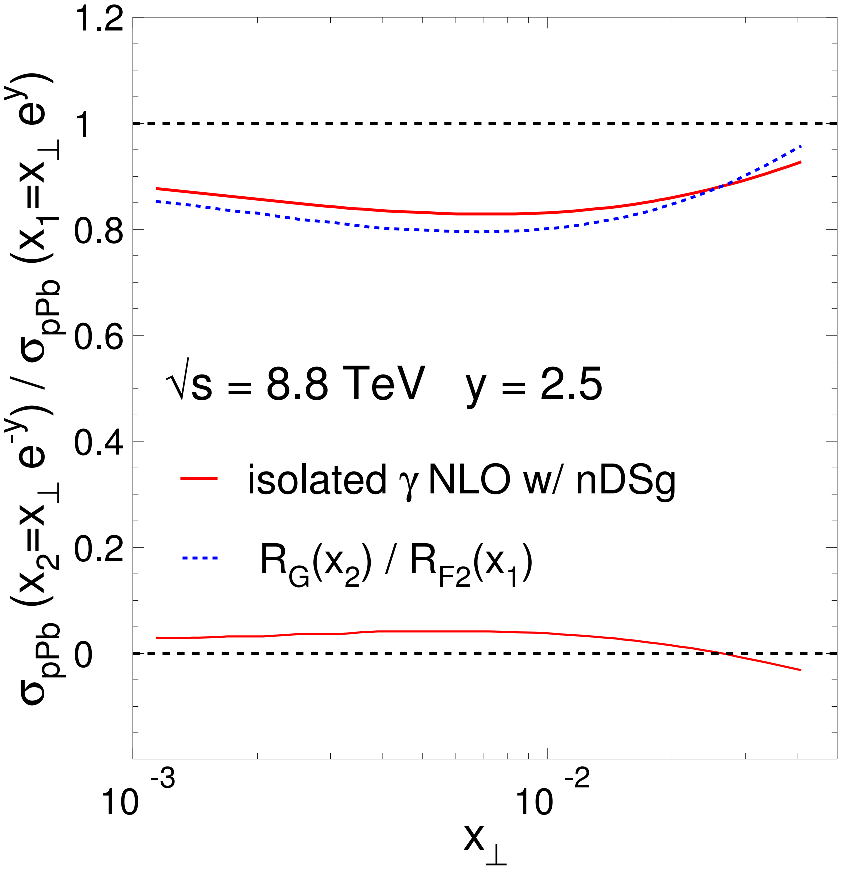
$$\simeq R_G(x_\perp e^{-y})/R_{F_2}(x_\perp e^{y})$$

R_{F_2} at large x gives access to R_G at small x !

Shadowing without p p data



- Encouraging yet a larger y would be better
- Need to correct for trivial isospin effects

Inclusive photons in A A collisions:

probing energy loss effects (?)

You said "energy loss" ?

Naively

Photons are not sensitive to quark-gluon plasma formation

because they are colour neutral ("initial-state observable")

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Photons are not sensitive to quark-gluon plasma formation

because they are colour neutral (“initial-state observable”)

. . . may not be that true because of

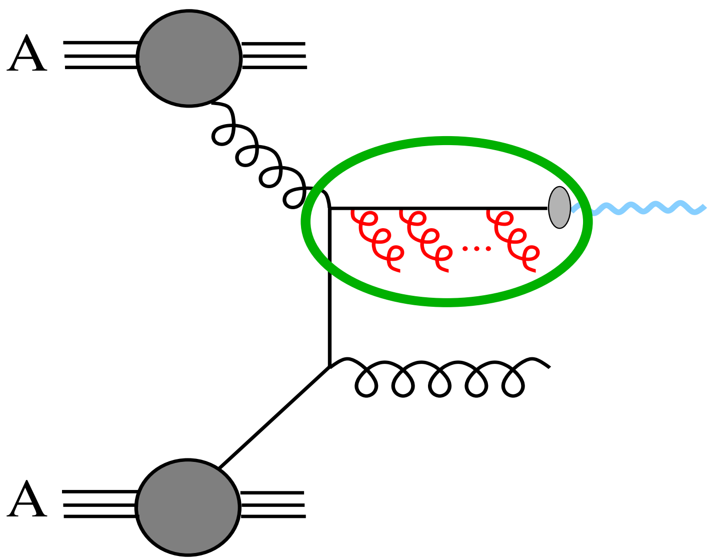
the fragmentation component

[NB: Recall however that “direct” and “fragmentation” photons is to a great extent arbitrary beyond LO]

The idea

The multiple scattering of hard partons leads to jet quenching

. . . may also apply for collinear photons



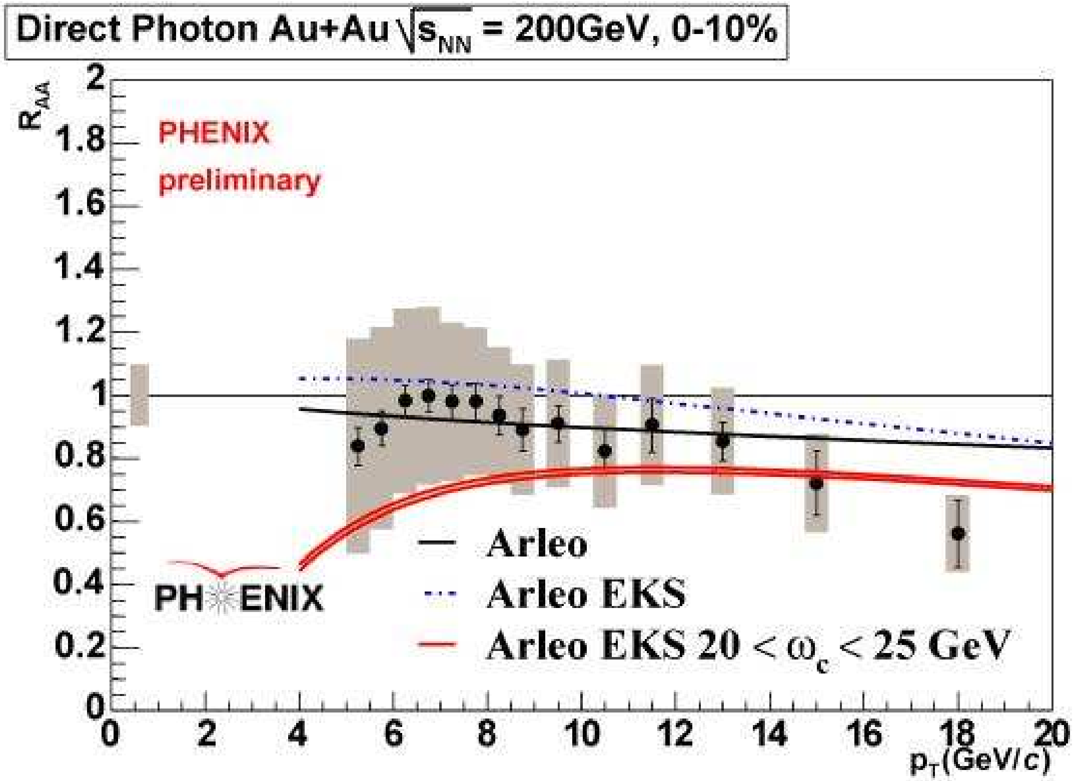
Jet quenching implies quenching of fragmentation photons !

[Jalilian-Marian, Orginos, Sarcevic 01]

[FA, Aurenche, Belghobsi, Guillet 04]

RHIC data

Quenching factors measured by PHENIX (preliminary)



[FA 2006]

- Data are slightly below 1 at large $p_\perp$
- Isospin does half the job at $p_\perp = 18$ GeV

RHIC data

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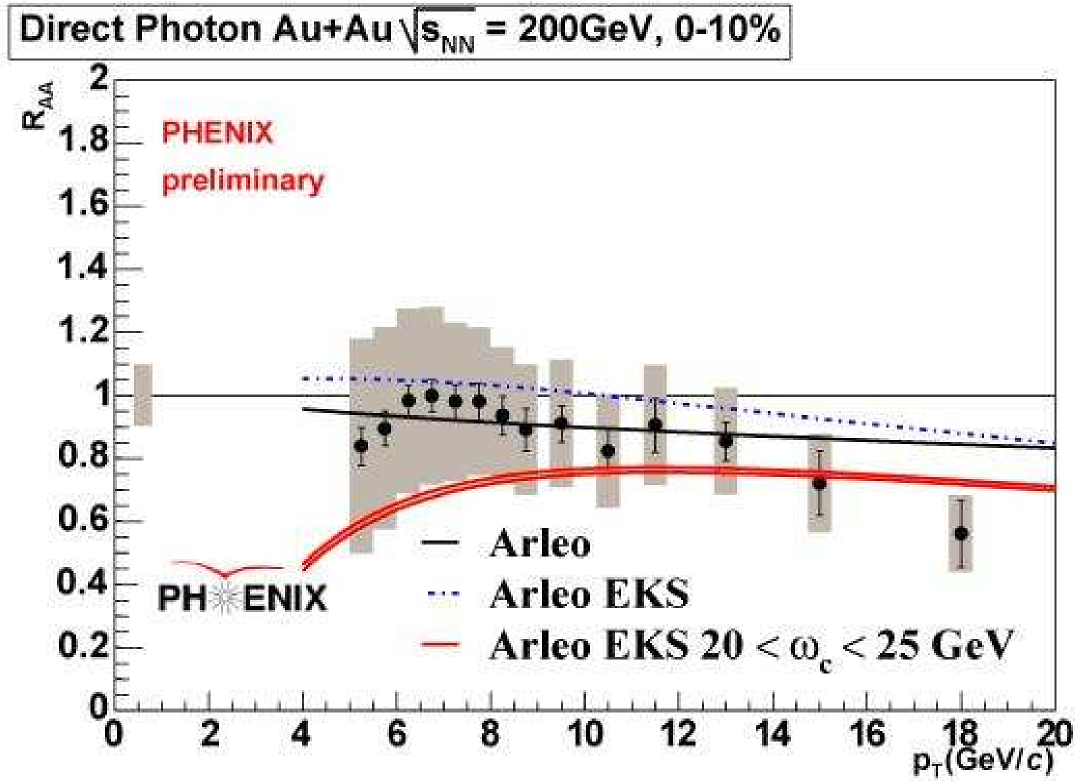


[FA 2006]

The medium seems to (slightly) suppress

the prompt photon yield in A A collisions

Extrapolating to LHC

In a Bjorken expansion (with $t_0 \ll L$)

$$\begin{aligned} \omega_c &\simeq \hat{q}(t_0)\, t_0\, L \\ &\sim Q_s^2 \sim \left(\sqrt{s_{\mathrm{NN}}}\right)^{\lambda} \end{aligned}$$

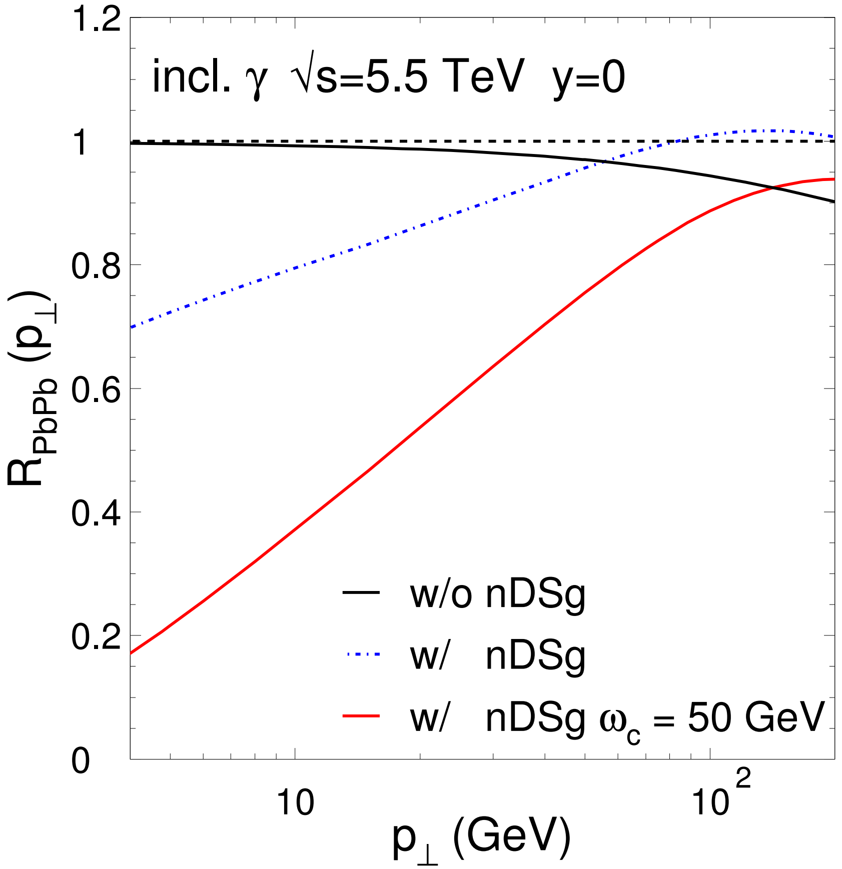
Using $\lambda = 0.3$ (DIS) and $\omega_c = 20$ GeV (RHIC)

$$\omega_c^{\mathrm{LHC}} \simeq 50 \text{ GeV}$$

The calculation is carried out at leading-order using

- CTEQ6M PDF
- nDSg nuclear distribution ratios
- BFG fragmentation functions into photons
- Modified w/ finite-energy BDMPS quenching weights
- All scales $M = \mu = M_F = p_\perp$

Predictions



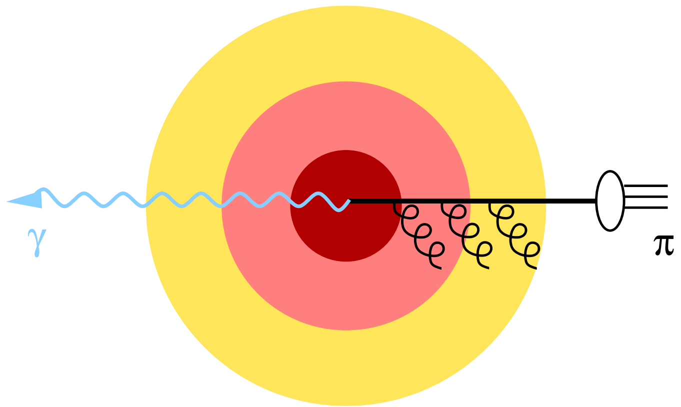
- Significant photon quenching below $p_\perp \lesssim 50$ GeV
- Weaker energy loss effects at forward rapidity

Photon-tagged correlations:

probing (medium) fragmentation functions

Momentum imbalance

To leading-order in α_s



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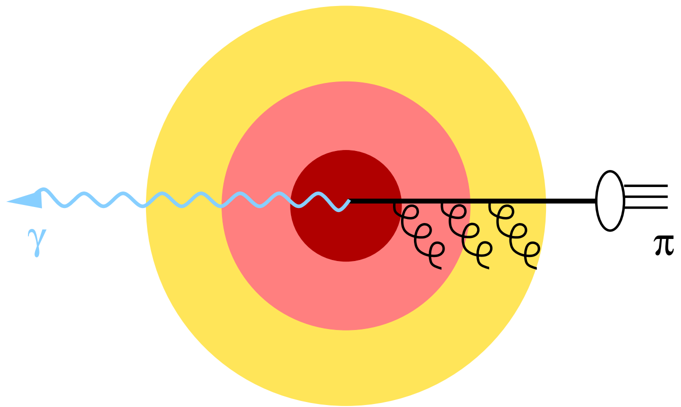


Introducing the momentum imbalance variable

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

LO kinematics

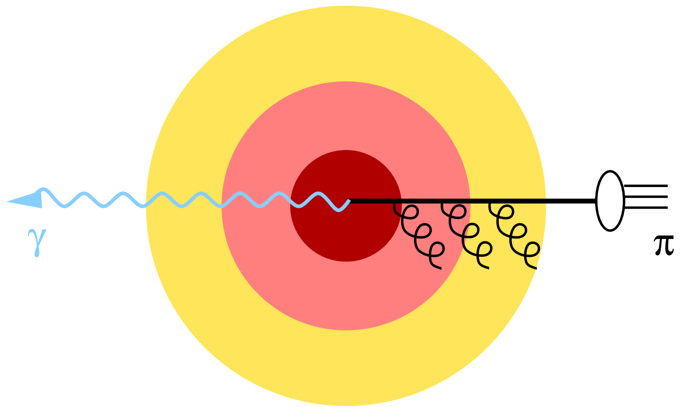
$$z_{\gamma\pi} \simeq \frac{p_{\perp_\pi}}{p_{\perp_\gamma}}$$

Momentum conservation

$$p_{\perp_\gamma} = k_\perp$$

Momentum imbalance

To leading-order in α_s



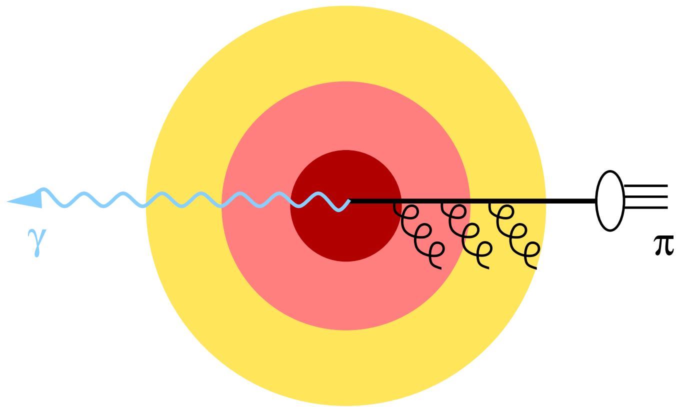
Introducing the momentum imbalance variable ...

... allows for the estimate of the fragmentation variable z !

(exp.) $z_{\gamma\pi} \Leftrightarrow z$ (th.)

Momentum imbalance

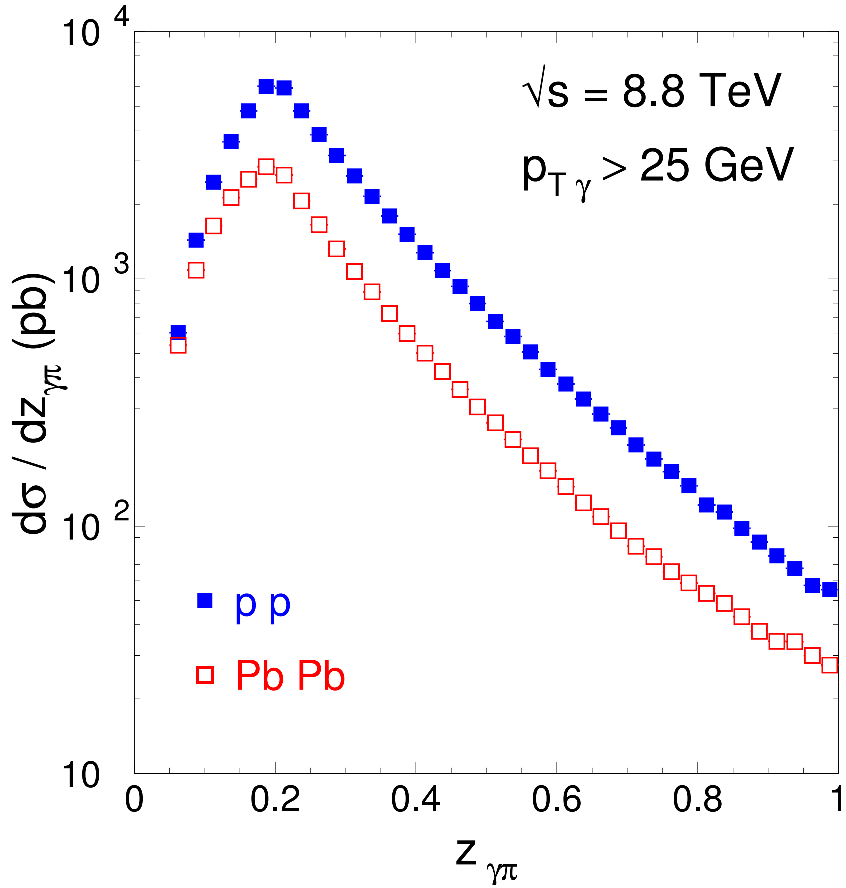
To leading-order in α_s



Momentum imbalance distributions in p p et A A collisions to probe fragmentation functions at LHC

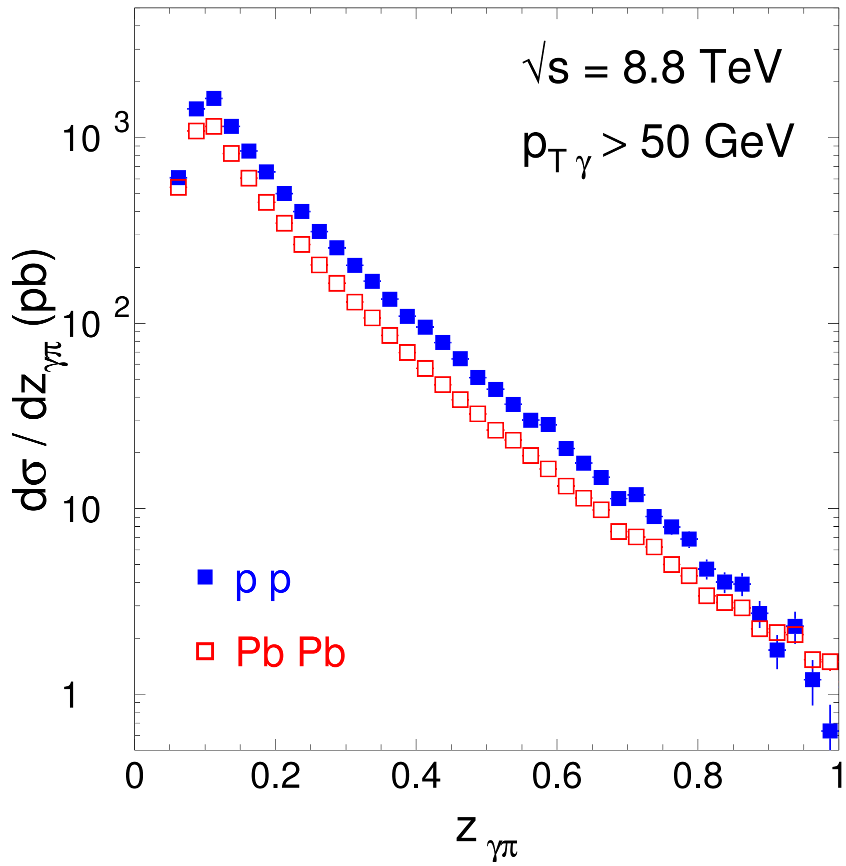
[Wang, Huang, Sarcevic 96]
[FA, Aurenche, Belghobsi, Guillet 04]

Predictions



- Reminiscent of the fragmentation functions
- The larger the $p_{\perp\gamma}^{\mathrm{cut}}$ the better

Predictions



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Multi-purpose prompt photons

- Isolated photons in p A collisions
  - efficient probe of gluon shadowing
  - R_G/R_{F_2} accessible without p p data at 8.8 TeV
- Inclusive photons in A A collisions
  - interplay of shadowing and (possible) energy loss effects
  - significant quenching at low $p_\perp$ at LHC
- Photon-tagged correlations
  - provide interesting constraints on (medium) fragmentation functions

Back-up

Pion quenching