Photon and charm production in the CGC framework

T. Lappi

University of Jyväskylä, Finland

Workshop: Low-x gluon structure of nuclei and signals of saturation at LHC

European Research Council
Established by the European Commission

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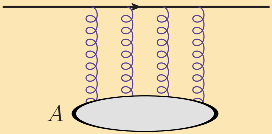
Outline

- Dilute-dense processes in CGC
- Charm
- Photons
- π^0 (light hadrons)
- Speculation about NLO

Calculations: Bertrand Ducloué, Heikki Mäntysaari

Eikonal scattering off target of glue



How to measure small-x glue?

- Dilute probe through target color field
- At high energy interaction is eikonal

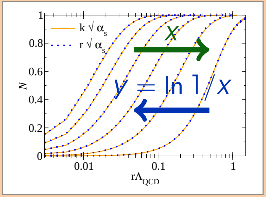
Eikonal scattering amplitude: Wilson line V

$$V = \mathbb{P}\exp\left\{-ig\int^{x^+} \mathrm{d}y^+ A^-(y^+, x^-, \mathbf{x}_T)\right\} \underset{x^+\to\infty}{\approx} V(\mathbf{x}_T) \in \mathrm{SU}(N_\mathrm{c})$$

- Amplitude for color dipole

$$\mathcal{N}\left(|\mathbf{x}_T - \mathbf{y}_T|\right) = 1 - \left\langle \frac{1}{N_\mathrm{c}} \mathrm{Tr}\, V^\dagger(\mathbf{x}_T) V(\mathbf{y}_T)\right\rangle$$

  from color transparency to saturation

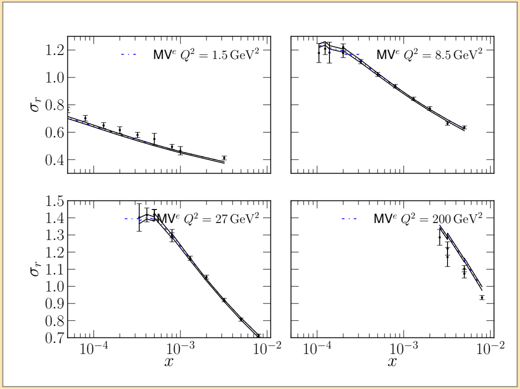


- $1/Q_\mathrm{s}$ is Wilson line **correlation length**, Q_s is gluon **intrinsic** k_T

Where to get Wilson lines?

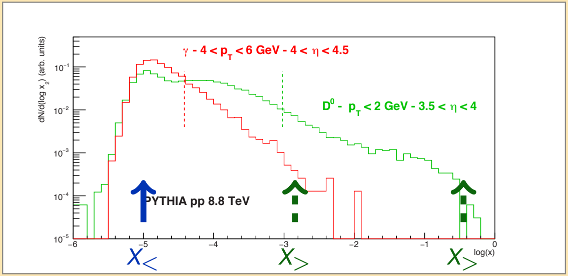
Use here MV^e parametrization, T.L., Mäntysaari, arXiv:1309.6963

- Initial condition for protons at $x_0 = 0.01$, 3 fit parameters
- $x < x_0$ prediction of rcBK evolution (1 fit parameter: scale in α_s)
- Fit to HERA F_2 data (same that determines collinear pdf's)
- Nuclei: optical Glauber at x_0: no additional parameters



Note on power counting and kinematics

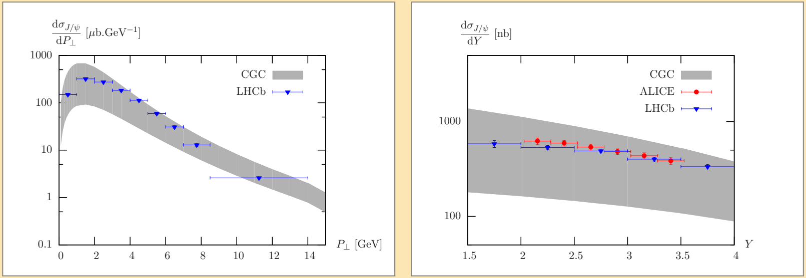
Collinear $2 \to 2$ process, measure only 1 particle:
integral over large rapidity interval $\Delta y = \ln \frac{x_>}{x_<}$



- In the CGC the power counting assumes $\alpha_s \ln \Delta y \sim 1$
  $\Longrightarrow$ integrated gluon absorbed into BFKL/BK/JIMWKL-evolved renormalized target at $x_<$
- The gluon recoil also gives intrinsic $\mathbf{k}_T$ $\Longrightarrow$ e.g. J/Ψ has p_T distribution at LO in CGC (vs. only at NLO in collinear)

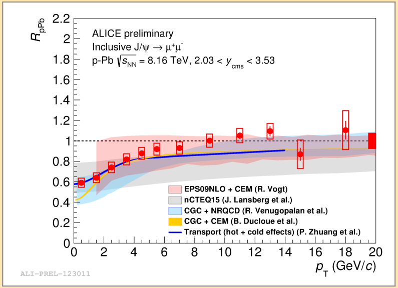
Inclusive J/ψ in LHCb/ALICE kinematics

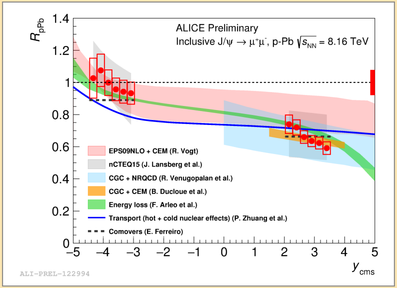
Cross sections for pPb Ducloué, T.L. Mäntysaari 1503.02789



Most of normalization uncertainty from scale in collinear PDF, and in α_s

R_{pA} for inclusive J/ψ



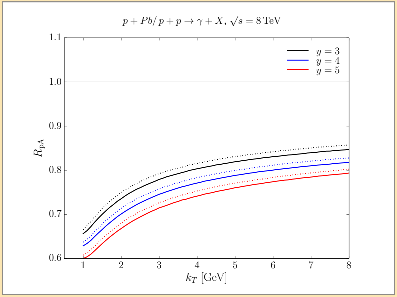


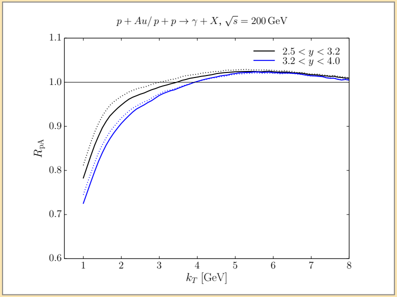
R_{pA}: scale uncertainty cancels

$\Longrightarrow$ determined by optical Glauber & value of Q_s (HERA)

Isolated photon R_{pA}

Ducloué, T.L. Mäntysaari, arXiv:1710.02206



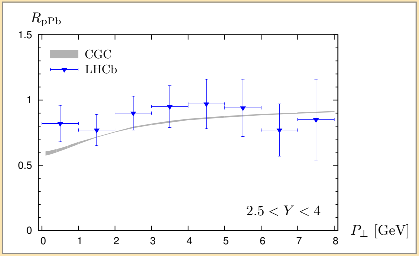


LHC energy

RHIC energy

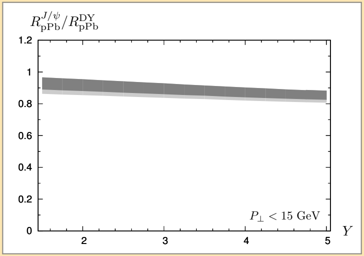
To see saturation effects at weak coupling p_T:
need LHC energy and preferrably fwd kinematics.

More R_{pA}'s: DY, D: very much same story



R_{pA} for D-mesons

Ducloué, T.L. Mäntysaari, `arXiv:1612.04585`

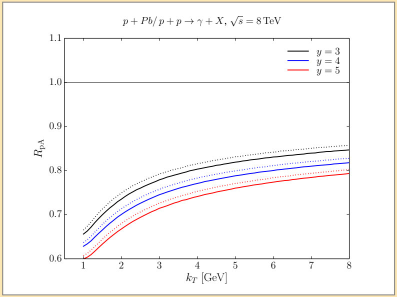


Double ratio of J/ψ to DY

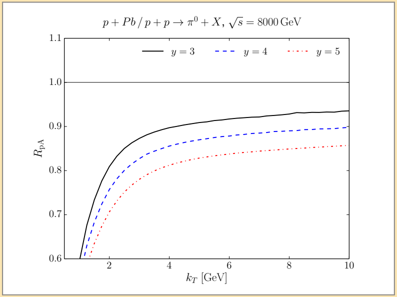
Ducloué `1701.08730`

(Cf. J/ψ energy loss models)

For comparison: light hadrons



Photons

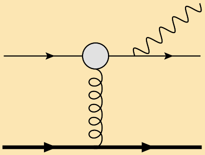


π^0: suppression not as large

Why is π^0 different?

Largely artefact of CGC power counting.
LO CGC processes are

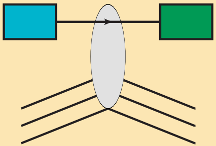
Photons



$1 \to 2$ kinematics:
even large photon k_T
can have target $k_T \sim Q_s$
$\Longrightarrow$ suppression

(Eventually need to resum Sudakov)

Pions



$1 \to 1$ kinematics:
large pion p_T always from
target $k_T \gg Q_s$
Becomes $1 \to 2$ at NLO

Conclusions

- By now quite large set of predictions for forward pA in same framework: light hadrons (with fragmentation functions) , real, virtual photons, heavy quarks
- Overall: predictions not that different from collinear QCD
  - PDF's are fit to same HERA data that CGC describes well
  - Intrinsically LO BK gives faster rapidity dependence: **predict fwd nuclear suppression**
- Caveats: calculations so far LO
  - Kinematics different for q, g vs. Q, γ processes
  - NLO BK evolution seems to freeze "anomalous dimension": expect y-dependence of R_{pA} will become closer to nuclear PDF's, but still no calculation . . .
    (Fourier-positivity + HERA data + NLO BK collinear resummation)

  Working on understanding these effects
  (but predicting difficult, particularly in advance)
- Big picture: also correlations, see Cyrille's talk!

Anomalous dimension

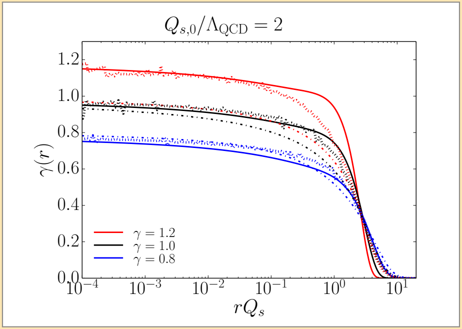
Recall initial condition: $N(r) = 1 - e^{-\frac{(r^2 Q_{s0}^2)^\gamma}{4} \ln\left(\frac{1}{r\Lambda_{QCD}} + e\right)}$,

Define

$$\gamma(r) \equiv -\frac{d \ln N(r)}{d \ln r^2}$$

Geometric scaling?

- LO: fast to $\gamma \sim 0.8$
- NLO: stay at initial γ



- Solid: initial condition
- Dotted: $y = 5$ NLO
- Dot-dashed: $y = 5$ LO (rc)

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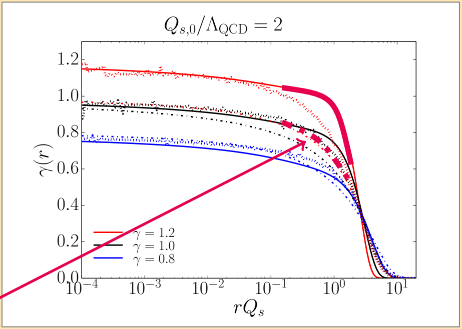

LO $y = 0$ to $y = 5$

- Solid: initial condition
- Dotted: $y = 5$ NLO
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