Diffractive D^0 photoproduction in ultraperipheral collisions at the LHC

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Outline | D^0 photoproduction in UPCs

Based on Caucal, G-E, Lappi, Salazar (in preparation),
Caucal, G-E, Iancu, Lappi, Salazar (2026)
and G-E, Lappi, Mäntysaari, PRD 111 (2025)

1) Motivation

2) Ingredients for UPC phenomenology

3) Theory: coherent diffraction in the dipole picture

4) Results
   a. Diffractive D^0 in Pb–Pb and p–Pb UPCs
   b. Inclusive D^0 in UPCs in the $Xn0n$ class

5) Summary

Charm photoproduction in UPCs | Motivation

Study gluon saturation at high energy within the Color Glass Condensate effective field theory

- Charm photoproduction, $m_c \approx 1.5$ GeV

  $\rightarrow$ sensitive to the saturation region at high energy

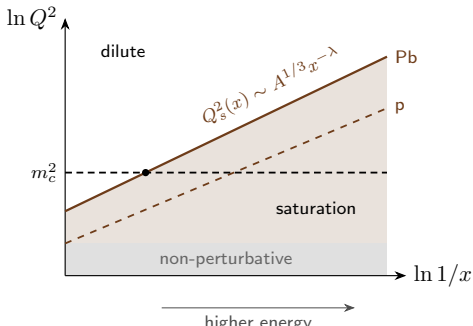
- Diffraction ($\sigma \propto |\mathcal{N}|^2$)

  $\rightarrow$ more sensitive to saturation than inclusive ($\sigma \propto \mathcal{N}$)

  $\mathcal{N}$: dipole–target scattering amplitude

- New inclusive D^0 data ($Xn0n$)

  $\rightarrow$ the theory need to subtract coherent diffraction ($0n0n$)



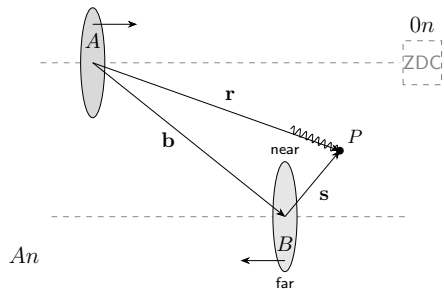
x: momentum fraction of the target gluon,

$$x \sim \frac{m_T}{\sqrt{s_{NN}}} e^{-y}$$

CMS, PRL 136 (2026), G-E, Lappi, Mäntysaari, PRD 111 (2025)

Ingredients for UPC phenomenology

- Photon flux $F(z_\gamma)$ includes:
  - Woods–Saxon charge distribution
  - Hadronic survival $\rightarrow$ no hadronic interaction
  - Probability of no electromagnetic dissociation $P(b)$:
    $An0n\colon P,\ \ 0n0n\colon P^2,\ \ Xn0n\colon P(1-P)$
- $c \rightarrow D^0$ fragmentation functions: BCFY, KK, HymnD
- Dipole amplitude $\mathcal{N}$: describes the scattering
  - Small-x evolution with the BK equation
  - Initial condition fitted to DIS HERA data



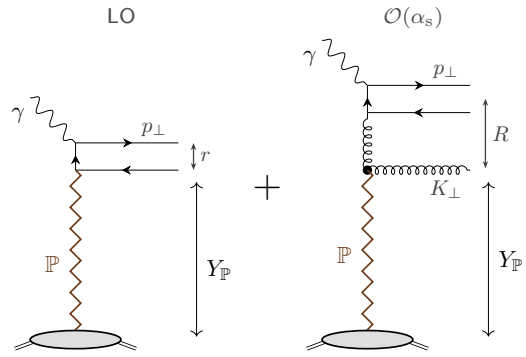
UPC in the $An0n$ class

FFs: BCFY, PRD 51 (1995), KK, PRD 74 (2006), HymnD (2026) Dipole: Lappi, Mäntysaari, PRD 88 (2013)

Coherent diffraction | Exclusive + diffractive$_{\text{TMD}}$

- Exclusive $\gamma A \to c\bar{c}A$
  - weak scattering ($r \sim 1/p_\perp$)
  - falls as $\sim p_\perp^{-8}$
- Diffractive $\gamma A \to c\bar{c}gA$
  - hard $c\bar{c}$ + semi-hard g ($p_\perp \gg K_\perp \sim Q_{\text{s}}$)
  - cross section factorized with TMDs
    TMD: transverse-momentum-dependent distribution
  - strong scattering ($R \sim 1/Q_{\text{s}}$)
  - falls as $\sim p_\perp^{-4}$

$\to$ diffractive$_{\text{TMD}}$ dominates



Exclusive

Diffractive$_{\text{TMD}}$

soft-quark contribution
also included ($< 1\%$)

TMD factorization: Caucal, G-E, Iancu, Lappi, Salazar (2026)

Diffractive D^0 in UPCs | Cross section

$$\frac{\mathrm{d}\sigma^{\text{diffractive}}_{\text{UPC}}}{\mathrm{d}y\,\mathrm{d}^2\mathbf{p}_D} = \int_0^1 \frac{\mathrm{d}z_h}{z_h^2}\, D(z_h) \int_{z_\gamma^{\min}}^1 \mathrm{d}z_\gamma\, F(z_\gamma)$$

($c \to D^0$ Fragmentation; Photon flux)

$$\times \left[\int_{x_{\mathbb{P}\,\min}(z_\gamma)}^{x_{\mathbb{P}\,\max}} \frac{\mathrm{d}x_{\mathbb{P}}}{x_{\mathbb{P}}} \frac{\mathrm{d}\sigma^{\text{diffractive}_{\text{TMD}}}_{\gamma+A}}{\mathrm{d}y\,\mathrm{d}^2\mathbf{p}\,\mathrm{d}\ln x_{\mathbb{P}}} \quad + \quad \Theta\big(x_{\mathbb{P}\,\max} - x_{\mathbb{P}}(z_\gamma)\big) \frac{\mathrm{d}\sigma^{\text{exclusive}}_{\gamma+A}}{\mathrm{d}y\,\mathrm{d}^2\mathbf{p}} \right]$$

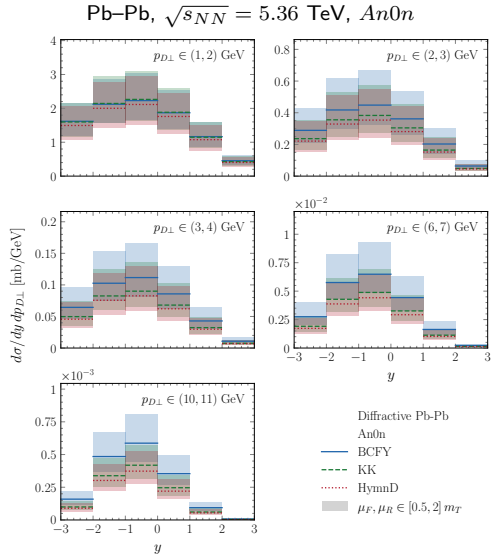
$x_{\mathbb{P}}$: momentum fraction of the target nucleon carried by the pomeron

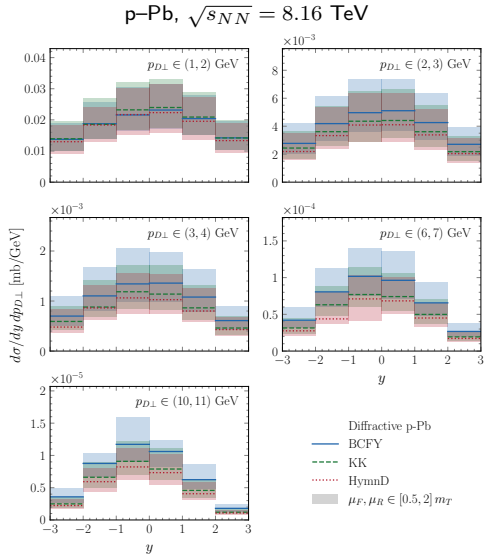
- Calculated in the color glass condensate and light-cone perturbation theory
- Diffractive$_{\text{TMD}}$ $\to$ valid for $p_\perp, m \gg Q_{\text{s}}$: only an estimate at $p_\perp \lesssim 2$ GeV

Caucal, G-E, Lappi, Salazar (in preparation)

Diffractive D^0 in UPCs | Predictions in $p_{D\perp}$ bins

See also: Guzey, Innocenti, Stašto, Strikman (2026)



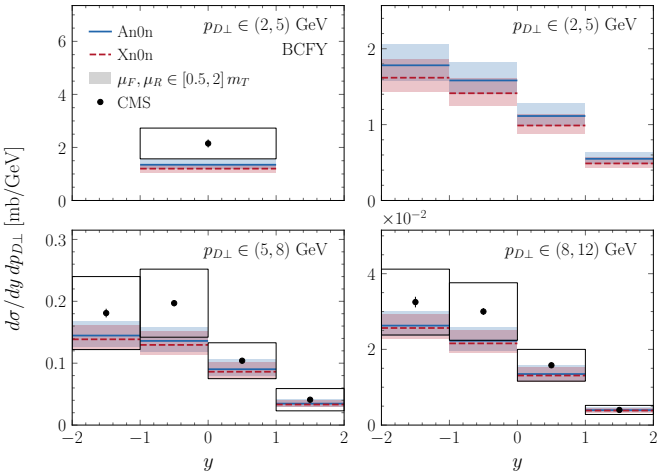


Inclusive D^0 in Pb–Pb UPCs | Comparison to CMS in the $Xn0n$ class

- Remove coherent diffraction (target intact)

$$\mathrm{d}\sigma^{\mathrm{incl}}_{Xn0n} = \mathrm{d}\sigma^{\mathrm{incl}}_{An0n} - \mathrm{d}\sigma^{\mathrm{diff}}_{0n0n}$$

- Correction at most $\sim 10\%$, at low $p_{D\perp}$
- For $p_{D\perp} > 5$ GeV: agreement with data
- Low $p_{D\perp}$: we underestimate the data
  $\rightarrow$ tension not resolved by diffraction



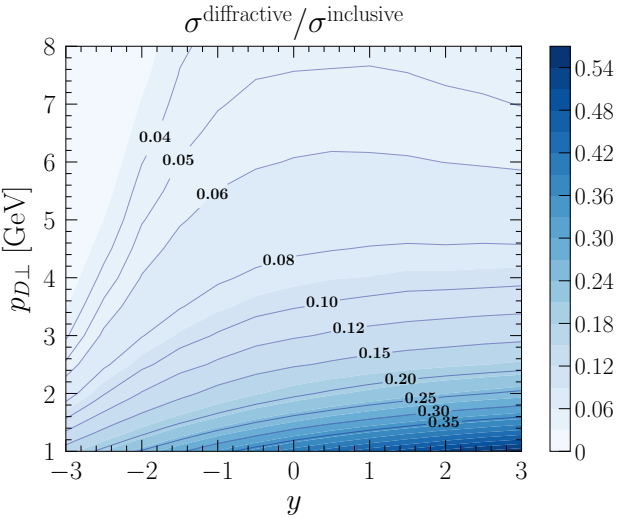
Inclusive D^0: G-E, Lappi, Mäntysaari, PRD 111 (2025), Data: CMS, PRL 136 (2026)

Diffractive vs. inclusive D^0 | Pb–Pb, $\sqrt{s_{NN}} = 5.36$ TeV, $An0n$, BCFY

- Ratio largest at low $p_{D\perp}$ and forward y
  - smaller $x_{\mathbb{P}}$, longer BK evolution

$$x_{\mathbb{P}} \sim \frac{m_T}{\sqrt{s_{NN}}}\, e^{-y}$$

- Large $p_{D\perp}$, backward y: a few %
  - diffractive spectrum falls faster

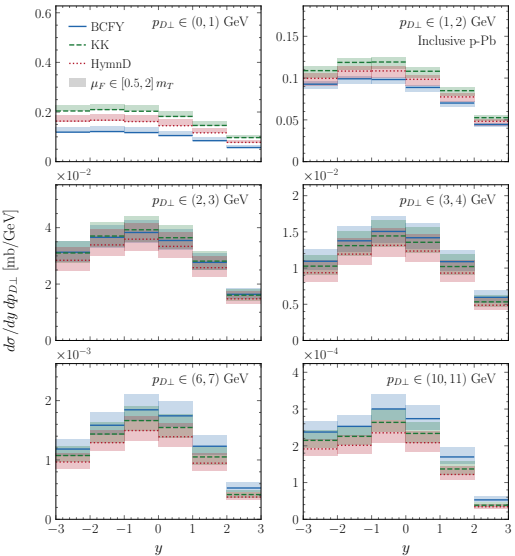


Inclusive D^0: G-E, Lappi, Mäntysaari, PRD 111 (2025)

Inclusive D^0 in p–Pb UPCs | Predictions, $\sqrt{s_{NN}} = 8.16$ TeV

- Photon emitted by Pb, proton target
- No neutron selection

  $\rightarrow$ no electromagnetic dissociation factor



Summary

- Coherent diffractive D^0 in Pb–Pb and p–Pb UPCs in the CGC
  - $\rightarrow$ $c\bar{c}g$ (gluon DTMD) dominates: exclusive suppressed by color transparency
  - $\rightarrow$ harder $p_{D\perp}$ spectrum than collinear diffractive PDFs
- Inclusive D^0 in the $Xn0n$ class
  - $\rightarrow$ diffractive correction $\sim 10\%$ at low $p_{D\perp}$
  - $\rightarrow$ agreement within uncertainties at high $p_{D\perp}$
- New: inclusive D^0 predictions for p–Pb UPCs
- Outlook: full NLO, back-to-back $D\bar{D}$ / D+jet (DTMDs), quarkonium