Diffractive dijet photoproduction at the EIC

Michael Klasen

Institute for Theoretical Physics, University of Münster

15 April 2021

2004.06972 and 2103.05419, in collaboration with V. Guzey

DFG

Graduiertenkolleg 2149
Research Training Group

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Introduction

Lessons from HERA:

- Jets provide important information α_s and gluon PDF
- Large fraction of events $(10 - 15\%)$ in DIS are diffractive
- QCD + Regge factorization $\rightarrow$ Pomeron PDFs

Open issue:

- Factorization breaking: Global or resolved photons only?

New topics:

- First measurement of diffractive nuclear PDFs
- Relation of diffraction to (cold) nuclear effects
- Information on virtual pion cloud in nuclei

The HERA collider at DESY

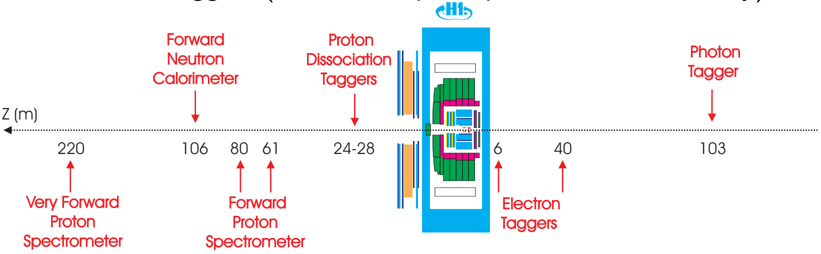
P. Newman, M. Wing, Rev. Mod. Phys. 86 (2014) 1037 [1308.3368]

The world's only *he* circular (*r*) facility (*a*):

- Only electrons (positrons) on protons, no Run III with nuclei
- Mostly 27.5 on 820 (920) GeV, last months 575 (460) GeV
- Important for F_L (high y, small x $\rightarrow$ BFKL dynamics?)

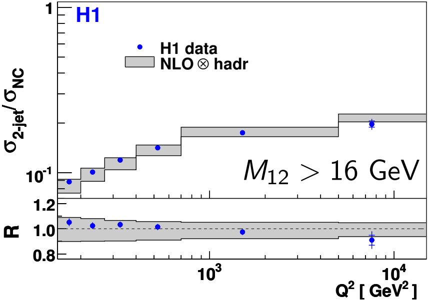
Detectors:

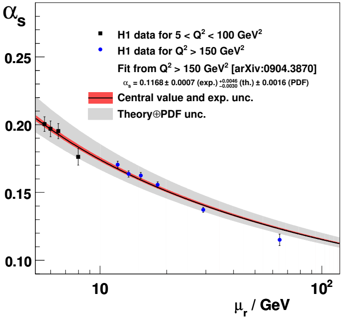
- Two general purpose detectors (H1, ZEUS)
- Microvertex detectors, tracking, calorimeters, muon chambers
- Forward taggers (diffraction, photoproduction, luminosity)



Fraction of dijet events in DIS and determination of α_s

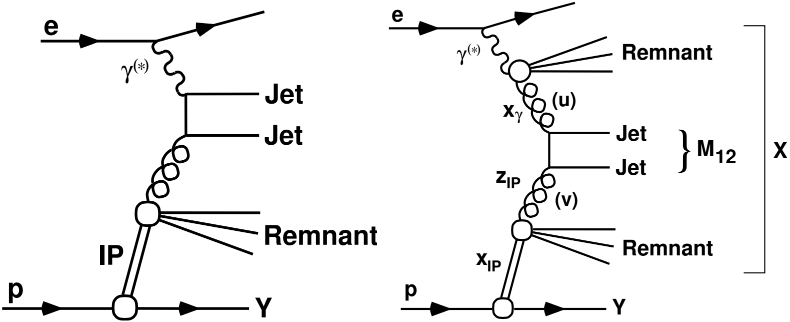
H1 Coll., Eur. Phys. C65 (2010) 363 [0904.3870]





Diffractive dijet photoproduction - direct and resolved

MK, G. Kramer, Mod. Phys. Lett. A23 (2008) 1885 [0806.2269]



X: Central hadronic system

$\updownarrow$: Large rapidity gap

Y: Forward proton (plus low-lying nucleon resonances)

Diffractive dijet photoproduction - experimental cuts

MK, G. Kramer, Mod. Phys. Lett. A23 (2008) 1885 [0806.2269]

Table 1. Kinematic cuts applied in the H1 analysis of diffractive dijet photoproduction.

165 GeV	$<$	W	$<$	242 GeV
		Q^2	$<$	0.01 GeV^2
		E_T^{jet1}	$>$	5 GeV
		E_T^{jet2}	$>$	4 GeV
-1	$<$	$\eta_{lab}^{jet1,2}$	$<$	2
		$x_{I\!P}$	$<$	0.03
		M_Y	$<$	1.6 GeV
		$-t$	$<$	1 GeV^2

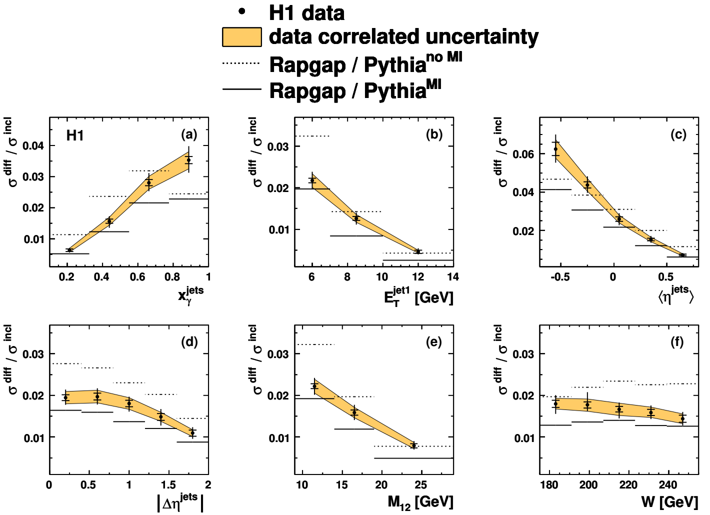
Table 2. Kinematic cuts applied in the ZEUS analysis of diffractive dijet photoproduction.

0.2	$<$	y	$<$	0.85
		Q^2	$<$	1 GeV^2
		E_T^{jet1}	$>$	7.5 GeV
		E_T^{jet2}	$>$	6.5 GeV
-1.5	$<$	$\eta_{lab}^{jet1,2}$	$<$	1.5
		$x_{I\!P}$	$<$	0.025
		$-t$	$<$	5 GeV^2

NB: Dissociative processes increase cross section by $1.15^{+0.15}_{-0.08}$.

Fraction of diffractive dijet events in photoproduction

H1 Coll., Eur. Phys. J. C70 (2010) 15 [1006.0946]



Diffractive parton distributions

H1 Coll., Eur. Phys. J. C48 (2006) 715 [hep-ex/0606004]

ZEUS Coll., Eur. Phys. J. C38 (2004) 43 [hep-ex/0408009]

Proof of QCD factorization: [J.C. Collins, Phys. Rev. D57 (1998) 3051]

$$\frac{d^2\sigma}{dx_{\boldsymbol{P}}dt} = \sum_a \int_x^{x_P} d\xi \sigma_a^{\gamma*}(x, Q^2, \xi) f_a^D(\xi, Q^2; x_{\boldsymbol{P}}, t)$$

Assumption of Regge factorization: [Ingelman, Schlein, Phys. Lett. B142 (1985) 256]

$$f_a^D(x, Q^2; x_{\boldsymbol{P}}, t) = f_{\boldsymbol{P}/p}(x_{\boldsymbol{P}}, t) f_{a/\boldsymbol{P}}(z_{\boldsymbol{P}} = x/x_{\boldsymbol{P}}, Q^2)$$

Pomeron flux factor:

$$f_{\boldsymbol{P}/p}(x_{\boldsymbol{P}}, t) = A_{\boldsymbol{P}} x_{\boldsymbol{P}}^{1-2\alpha_P(t)} \exp(B_{\boldsymbol{P}} t) \quad \text{with} \quad \alpha_{\boldsymbol{P}}(t) = \alpha_{\boldsymbol{P}}(0) + \alpha'_{\boldsymbol{P}} t$$

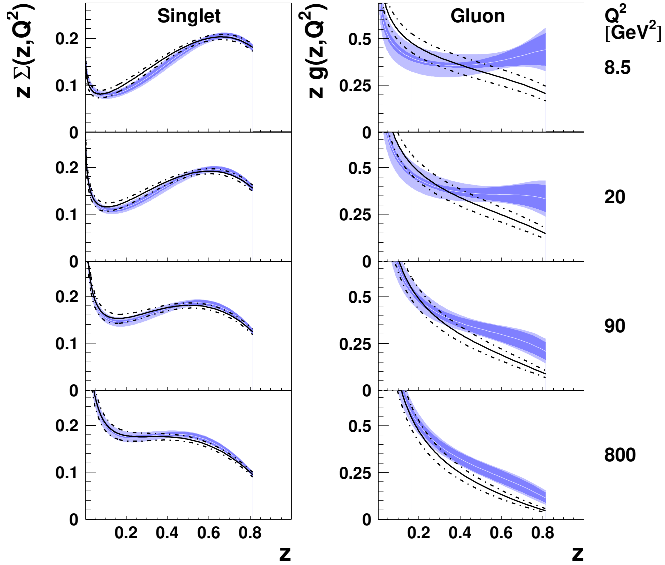
HERA determinations:

- H1: $B_{\boldsymbol{P}} = 5.5\,\text{GeV}^{-2}, \alpha'_{\boldsymbol{P}} = 0.06\,\text{GeV}^{-2}, \alpha_{\boldsymbol{P}}(0) = 1.111$ (Fit B)
- ZEUS: $B_{\boldsymbol{P}} = 4.67$ GeV^{-2}, $\alpha'_{\boldsymbol{P}} = 0.25$ GeV^{-2}, $\alpha_{\boldsymbol{P}}(0) = 1.16$

Dijet and open charm production in DIS well described.

Comparison of H1 2006 Fits A and B

H1 Coll., Eur. Phys. J. C48 (2006) 715 [hep-ex/0606004]



Diffractive photoproduction of dijets at the EIC

V. Guzey, M. Klasen, JHEP 05 (2020) 074

Experimental conditions:

- Electron-proton collisions with 21 GeV $\times$ 100 GeV
- Diffraction: $M_Y < 1.6$ GeV, $|t| < 1$ GeV^2, $x_{IP} < 0.03$
- Photoproduction: $Q^2 < 0.1$ GeV^2, $0 < y < 1$
- Jet definition ($\sim$ H1): Anti-k_T ($R = 1$), $p_{T1,2} > 5$ (4.5) GeV

Theoretical input:

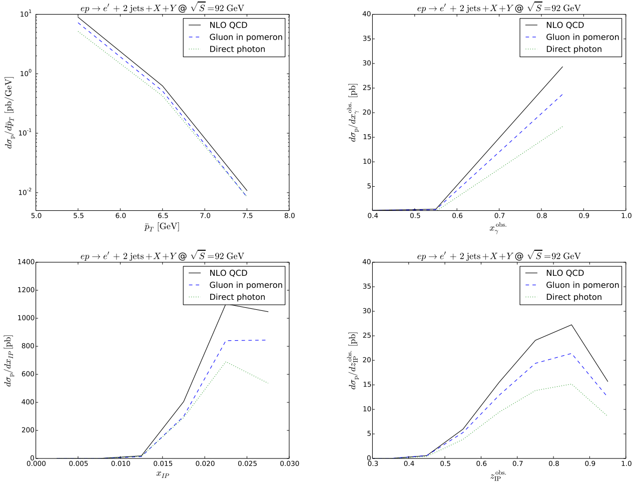
- Improved Weizsäcker-Williams photon spectrum
- Photon PDFs: GRV HO
- Diffractive PDFs: H1 2006 Fit B (Fit A, ZEUS 2009 Fit SJ)
- Scales: $\mu_R = \mu_F = \bar{p}_T$.

Important observables:

$$z_{IP}^{\rm obs} = \frac{p_{T,1}\, e^{\eta_1} + p_{T,2}\, e^{\eta_2}}{2 x_{IP} E_p} \quad , \quad x_\gamma^{\rm obs} = \frac{p_{T,1}\, e^{-\eta_1} + p_{T,2}\, e^{-\eta_2}}{2 y E_e}$$

Diffractive photoproduction of dijets at the EIC

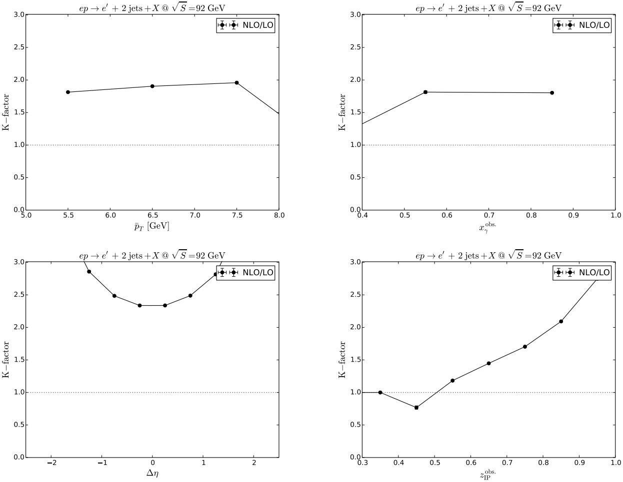
V. Guzey, M. Klasen, JHEP 05 (2020) 074



$p_T \leq 8$ GeV (HERA: 14 GeV) $\to$ Direct γ/pointlike $q\bar{q}$ dominate.
Production of dijet system requires also large $x_{\mathbb{P}}$ and $z_{\mathbb{P}}^{\mathrm{obs.}}$.

K-factors for diffractive dijet photoproduction

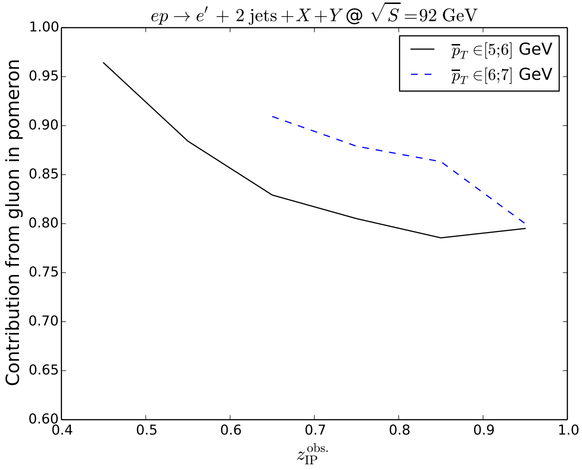
V. Guzey, M. Klasen, JHEP 05 (2020) 074



NLO/LO K-factor is ~ 2, even larger at kinematic edges.
Inclusive aNNLO/NLO K-factor is $\sim 1.12 \to$ pQCD converges.

Evolution of gluon in pomeron contribution

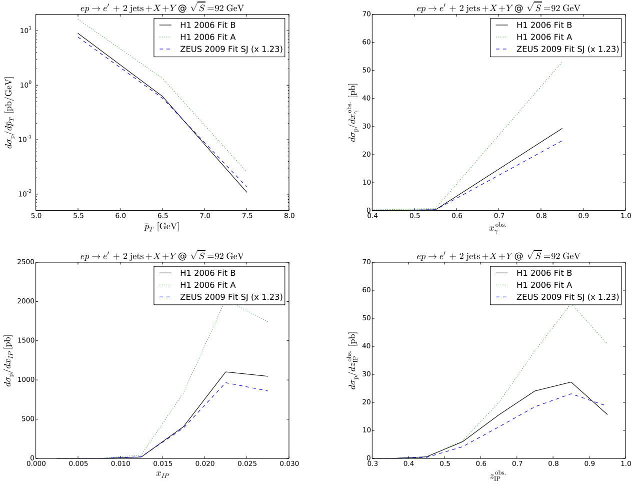
V. Guzey, M. Klasen, JHEP 05 (2020) 074



Corresponds to scale evolution of H1 2006 Fit B (flat for Fit A!).

Comparison of H1/ZEUS diffractive PDF fits

V. Guzey, M. Klasen, JHEP 05 (2020) 074

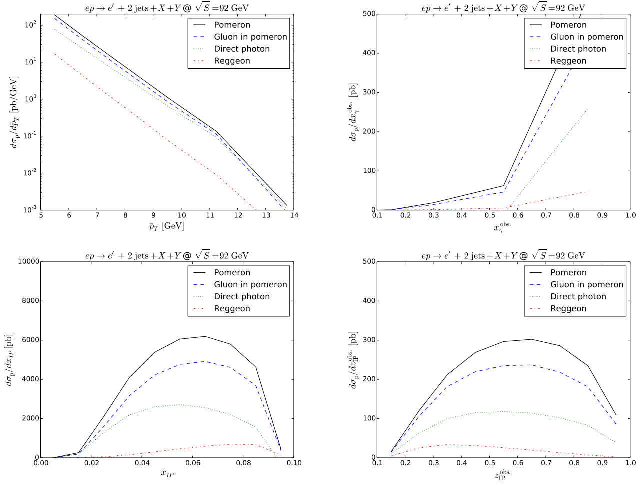


H1 2006 Fit A: $Q_0^2 = 1.75$ GeV^2, $C_g = -0.95 \pm 0.20$ (ZEUS 2009 Fit SJ: $C_g = -0.725 \pm 0.082$).

H1 2006 Fit B: $Q_0^2 = 2.50$ GeV^2, $C_g = 0$ (H1 2007 Fit Jets: $C_g = 0.91 \pm 0.18$).

Extension from $x_{\boldsymbol{P}} < 0.03$ to $x_{\boldsymbol{P}} < 0.10$

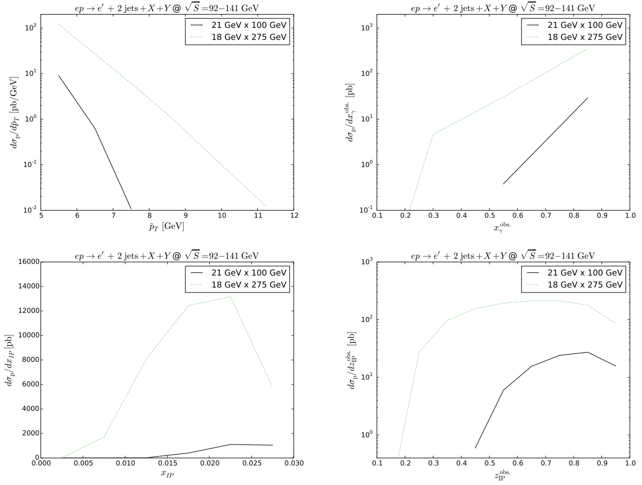
V. Guzey, M. Klasen, JHEP 05 (2020) 074



$$f_{i/p}^D(x, Q^2, x_{\boldsymbol{P}}, t) = f_{\boldsymbol{P}/p}(x_{\boldsymbol{P}}, t) \cdot f_{i/\boldsymbol{P}}(z_{\boldsymbol{P}}, Q^2) \; + \; n_{\boldsymbol{R}} \cdot f_{\boldsymbol{R}/p}(x_{\boldsymbol{P}}, t) \cdot f_{i/\boldsymbol{R}}(z_{\boldsymbol{P}}, Q^2)$$

Comparison with higher CMS energy

V. Guzey, M. Klasen, JHEP 05 (2020) 074



p_T now $\leq$ 12 GeV (HERA: 14 GeV) $\rightarrow$ Also resolved γ contributes.
x_P and $z_P^{\text{obs.}}$ no longer peaked at kinematic boundary.

A fresh look at factorization breaking in photoproduction

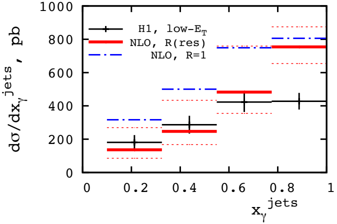
MK, V. Guzey, Eur. Phys. J. C76 (2016) 467 [1606.01350]

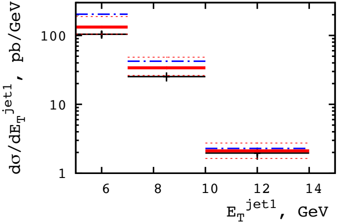
- Soft inelastic photon-proton interactions destroy rapidity gap
- Interaction strength depends on γ components (γ/VMD/$q\bar{q}$)
- Expect $S^2 = 1$ (γ), $S^2 = 0.34$ (VMD), $S^2 = 0.53 - 0.75$ ($q\bar{q}$)

[A. Kaidalov et al., Eur. Phys. J. C66 (2010) 373]

- Open charm not suppressed ($J/\psi \ll \rho, \omega, \phi$ in GVMD)
- Linear interpolation from small to large x_γ:

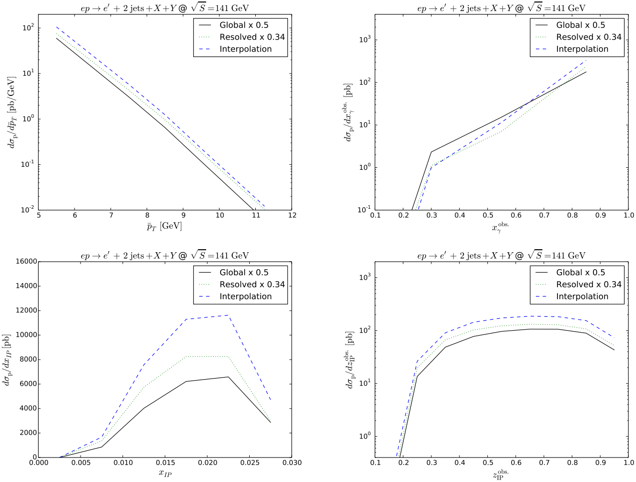
$$S_i^2(x_\gamma) \to \begin{cases} 1\,, & i = c\,, \\ A_q\, x_\gamma + 0.34\,, & i = u, d, s\,, \quad A_q = 0.37 - 0.41 \\ A_g\, x_\gamma + 0.34\,, & i = g\,, \quad\quad\;\; A_g = 0.19 - 0.24 \end{cases}$$





Comparison of factorization breaking schemes

V. Guzey, M. Klasen, JHEP 05 (2020) 074



At low $x_\gamma^{\mathrm{obs.}}$: Interpolation $\sim$ Resolved $<$ Global.
At medium $x_\gamma^{\mathrm{obs.}}$: Interpolation $\sim$ Global $>$ Resolved.

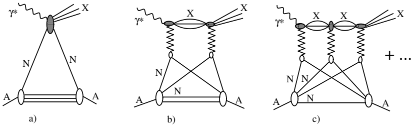
Diffractive PDFs in nuclei

L. Frankfurt, V. Guzey, M. Strikman, Phys. Rept. 512 (2012) 255

Defined similarly to those for nucleons:

$$F_{2A}^{D(3)}(x, Q^2, x_{\mathbb{P}}) = \int_{-1\,\mathrm{GeV}^2}^{t_{\min}} dt\, F_{2A}^{D(4)}(x, Q^2, x_{\mathbb{P}}, t) = \beta \sum_{j=q,\bar{q},g} \int_{\beta}^{1} \frac{dy}{y} C_j(\frac{\beta}{y}, Q^2) f_{j/A}^{D(3)}(y, Q^2, x_{\mathbb{P}})$$

Beyond IA (a) interactions with many nucleons N (b,c,...):



Use exp. t-depend. (B_{diff}), nucl. density $T_A(b) = \int dz \rho_A(b, z)$:

$$\beta f_{j/A}^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) = 4\pi A^2 B_{\mathrm{diff}}\, \beta f_{j/N}^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) \int d^2 b \left| \int_{-\infty}^{\infty} dz e^{i x_{\mathbb{P}} m_N z} e^{-\frac{A}{2}(1-i\eta)\sigma_{\mathrm{soft}}^{j}(x, Q^2) \int_z^{\infty} dz' \rho_A(b, z')} \rho_A(b, z) \right|^2$$

Regge factorization explicitly broken ($x = \beta x_{\mathbb{P}}$). Assume small $x_{\mathbb{P}}$:

$$\beta f_{j/A}^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) \approx 16\pi B_{\mathrm{diff}}\, \beta f_{j/N}^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) \int d^2 \vec{b} \left| \frac{1 - e^{-\frac{A}{2}(1-i\eta)\sigma_{\mathrm{soft}}^{j}(x, Q^2) T_A(b)}}{(1 - i\eta)\sigma_{\mathrm{soft}}^{j}(x, Q^2)} \right|^2$$

Diffractive nuclear PDFs at the LHC

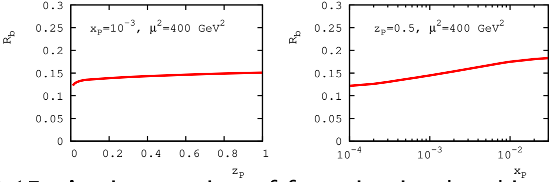
MK, V. Guzey, JHEP 1604 (2016) 158 [1603.06055]

$pA \sim pp$, scaled by $(1/2)Z^2(0.7\ \mathrm{fm}/R_A) \approx 350 \rightarrow$ Consider AA.

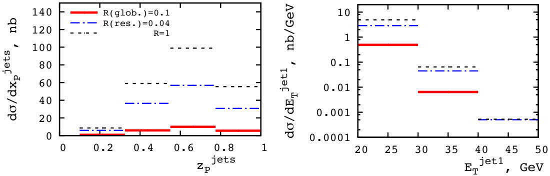
Diffractive nuclear PDFs in the impulse approximation (IA):

$$f_{j/A}^{D(4),\mathrm{IA}}(\beta, Q^2; x_{\boldsymbol{P}}, t) = A^2 F_A^2(t) f_{j/N}^{D(4)}(\beta, Q^2; x_{\boldsymbol{P}}, t_{\min})$$

Shadowing only weakly dependent on flavor j, $\beta = z_{\boldsymbol{P}}$, Q^2, $x_{\boldsymbol{P}}$:

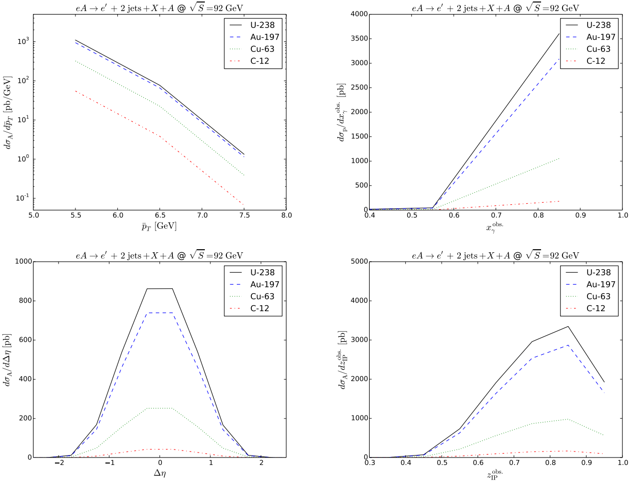


Use $R \simeq 0.15$. Again question of factorization breaking:



Cross sections for different nuclei

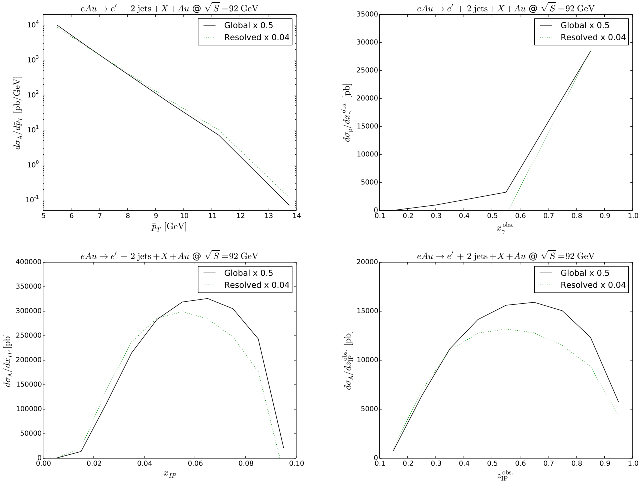
V. Guzey, M. Klasen, JHEP 05 (2020) 074



Diffractive PDFs for different nuclei scale with $AR(x, A)$.
H1 2006 Fit B corrected for no diffractive dissociation.

Comparison of factorization breaking schemes

V. Guzey, M. Klasen, JHEP 05 (2020) 074



Use larger $x_{\boldsymbol{P}}$ range to enhance resolved contribution.
Two-channel eikonal model suggests $S = 0.04$.

Conclusion

Lessons learned from HERA:

- Determination of diffractive PDFs in inclusive DIS
- Factorization holds for charm, jets $\rightarrow$ H1 2007 Fit Jets
- Factorization broken in γp ($\sim \bar{p}p$) $\rightarrow$ Global or VMD/$q\bar{q}$?

Lessons learned from LHC:

- Suppression depends on CMS energy
- UPCs provide access to photoproduction (incl. and diffr.)

Perspectives for the EIC:

- First determination of nuclear diffractive PDFs in DIS
- Access to gluon through F_L, test of Regge factorization
- Jet photoproduction important for test of QCD factorization
- Additional information on diffractive nuclear gluon density
- Test of leading-twist nuclear shadowing model