Perspectives on diffractive jet production at the EIC

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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

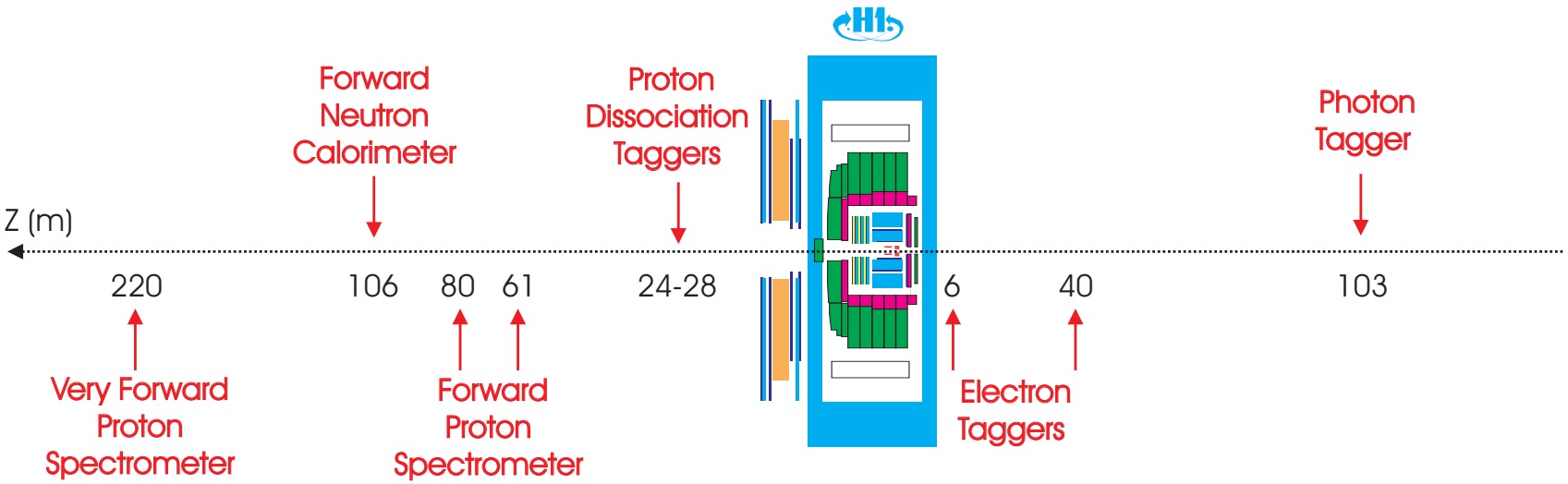
P. Newman, M. Wing, Rev. Mod. Phys. 86 (2014) 1037 [1308.3368]

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 $x \to$ BFKL dynamics?)

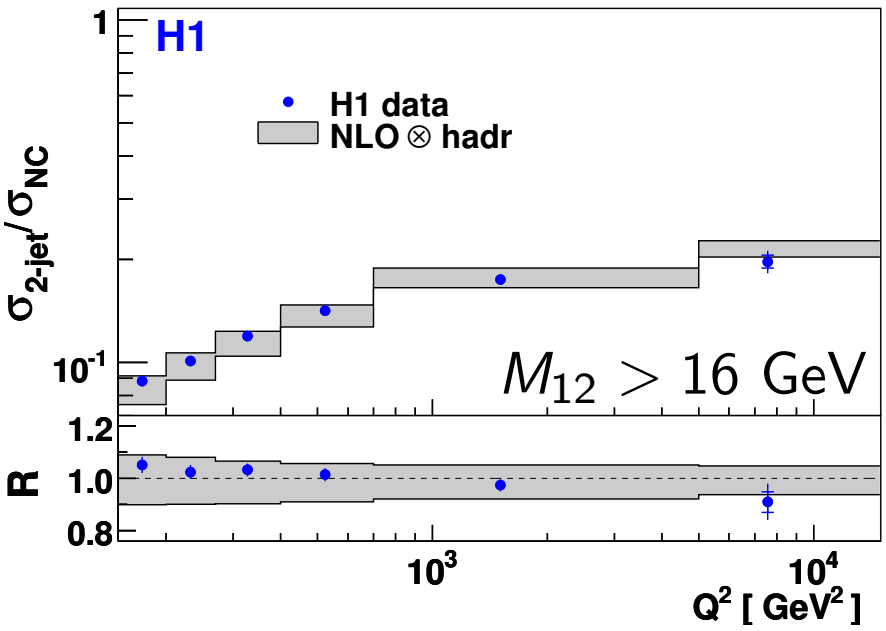
Detectors:

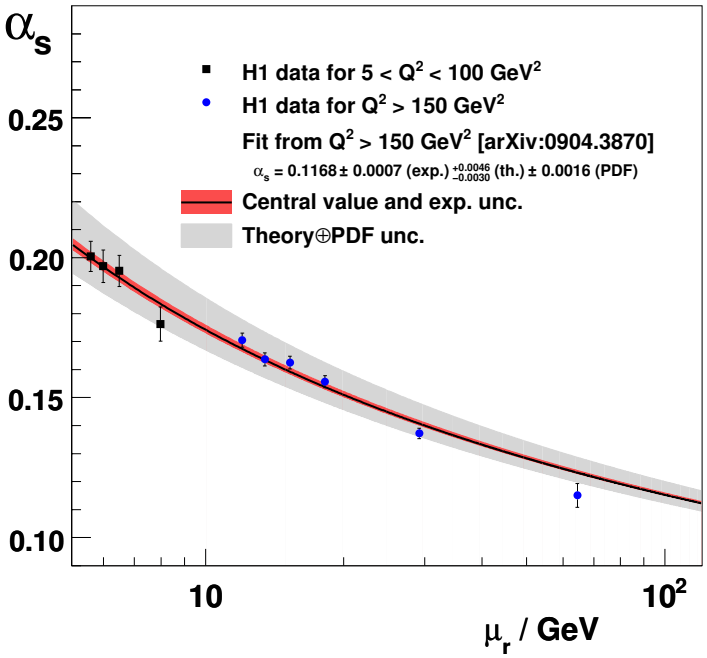
- Two general purpose detectors (H1, ZEUS)
- Microvertex detectors, tracking, calorimeters, muon chambers
- Forward taggers (diffraction, photoproduction, luminosity)



Fraction of dijet events in DIS and determination of α_s

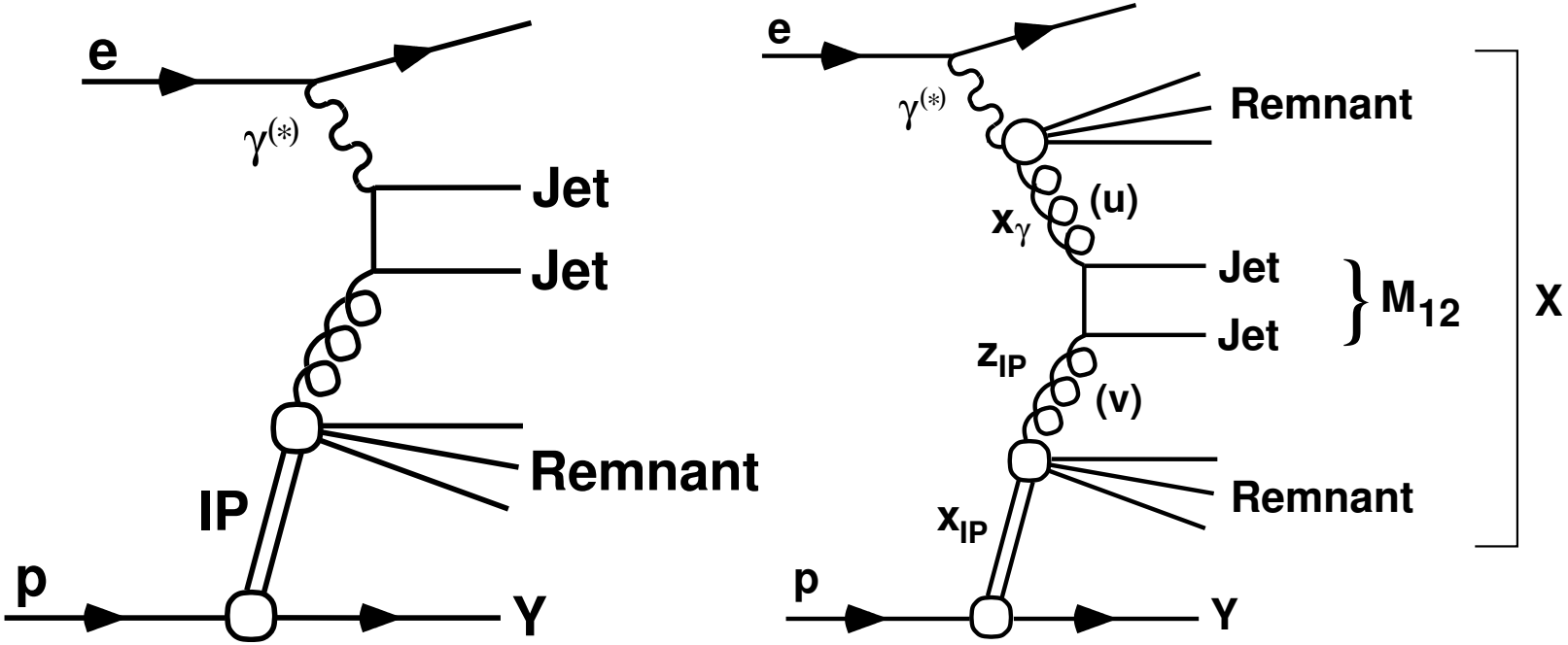
H1 Coll., Eur. Phys. C65 (2010) 363 [0904.3870]





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

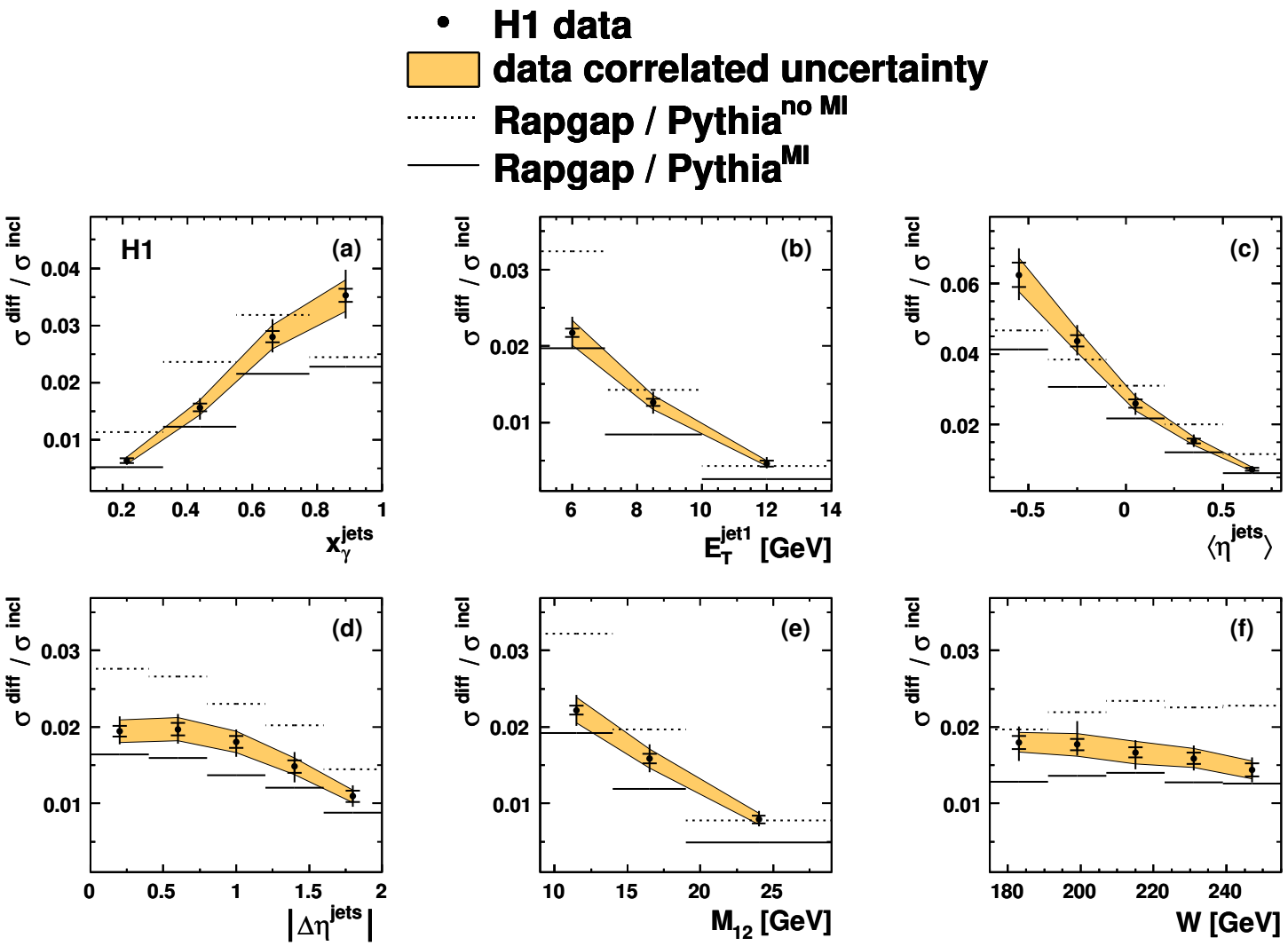
Table 2. Kinematic cuts applied in the ZEUS analysis of diffractive dijet photoproduction.

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:

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

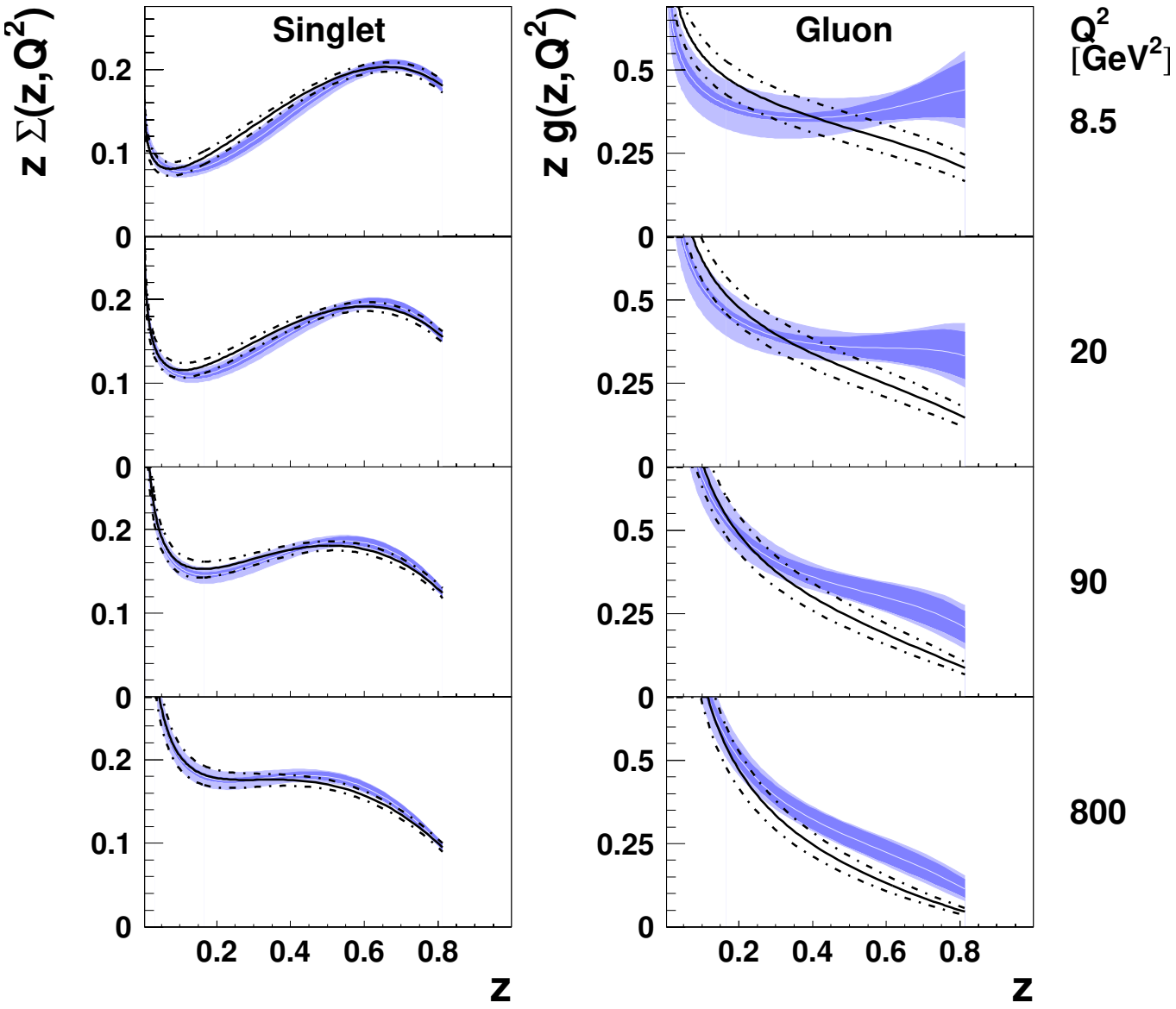
HERA determinations:

- 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: $B_{\boldsymbol{P}} = 4.67\ \text{GeV}^{-2}$, $\alpha'_{\boldsymbol{P}} = 0.25\ \text{GeV}^{-2}$, $\alpha_{\boldsymbol{P}}(0) = 1.16$

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]



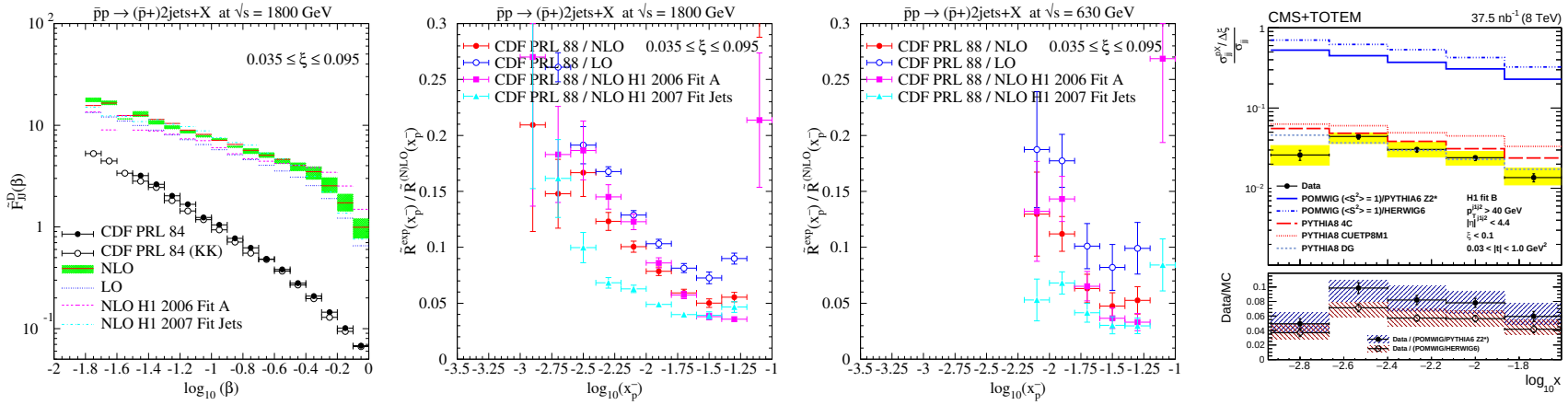
Factorization in diffractive DIS and its breaking in $\bar{p}p$

MK, G. Kramer, Phys. Rev. D80 (2009) 074006 [0908.2531]

- Deep-inelastic scattering: QCD factorization proven (Regge?)
- $\bar{p}p$ scattering at 1.8 TeV: Factorization broken by $\sim 1/10$
- Effective diffractive structure function F_{JJ}^{D}:

$$R(x,\xi,t) \approx \frac{F_{\mathrm{JJ}}^{\mathrm{D}}(x,Q^2,\xi,t)}{F_{\mathrm{JJ}}^{\mathrm{ND}}(x,Q^2)} \quad \text{with} \quad F_{\mathrm{JJ}}^{\mathrm{ND}}(x) = x[g(x) + \frac{4}{9}\sum_i q_i(x)]$$

using GRV 98 LO for F_{JJ}^{ND}.

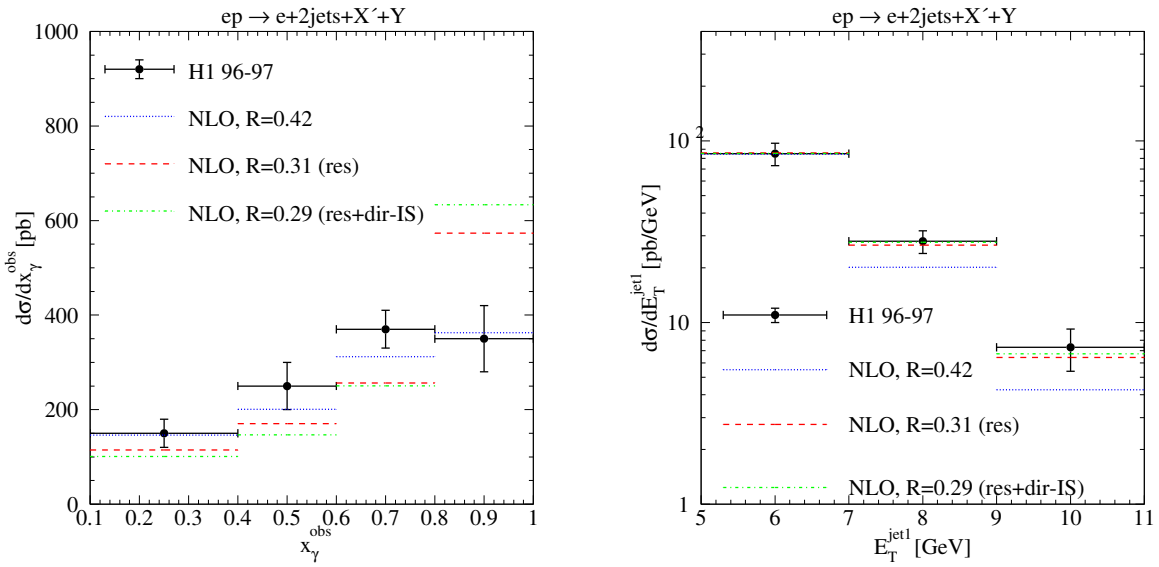


- 2-channel eikonal model (14 TeV): 1/20 [V. Khoze et al., EPJC 18 (2000) 167]

Factorization breaking in photoproduction

MK, G. Kramer, J. Phys. G31 (2005) 1391 [hep-ph/0506121]

- Photoproduction: Direct ($\sim$ DIS) + resolved ($\sim$ hh) processes
- Factorization breaking: Global or resolved photons only?



- Suppression of dir-IS collinear remainder:

$$M(Q^2,R)_{\overline{\mathrm{MS}}} = \left[-\frac{1}{2N_c}P_{q_i\leftarrow\gamma}(z)\ln\left(\frac{M_\gamma^2 z}{p_T^{*2}(1-z)}\right)+\frac{Q_i^2}{2}\right]R - \frac{1}{2N_c}P_{q_i\leftarrow\gamma}(z)\ln\left(\frac{p_T^{*2}}{zQ^2+y_s s}\right)$$

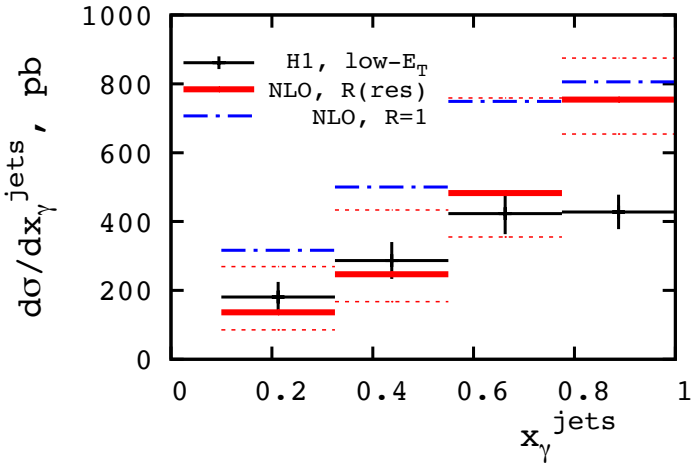
A fresh look at factorization breaking in photoproduction

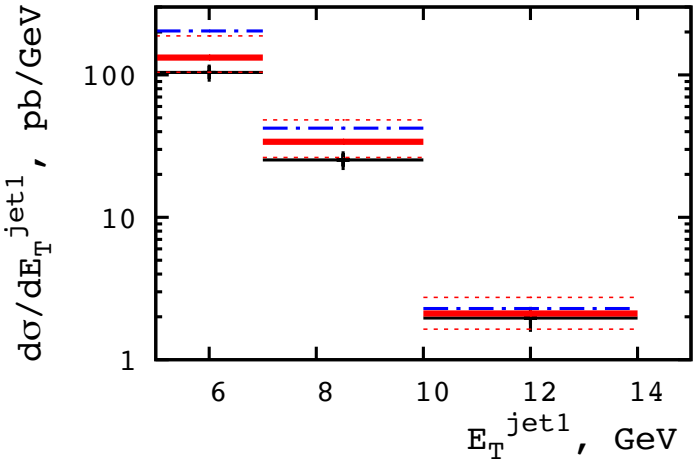
MK, V. Guzey, Eur. Phys. J. C76 (2016) 467 [1606.01350]

- 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:

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





Diffractive photoproduction of dijets at the EIC

V. Guzey, M. Klasen, in preparation

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:

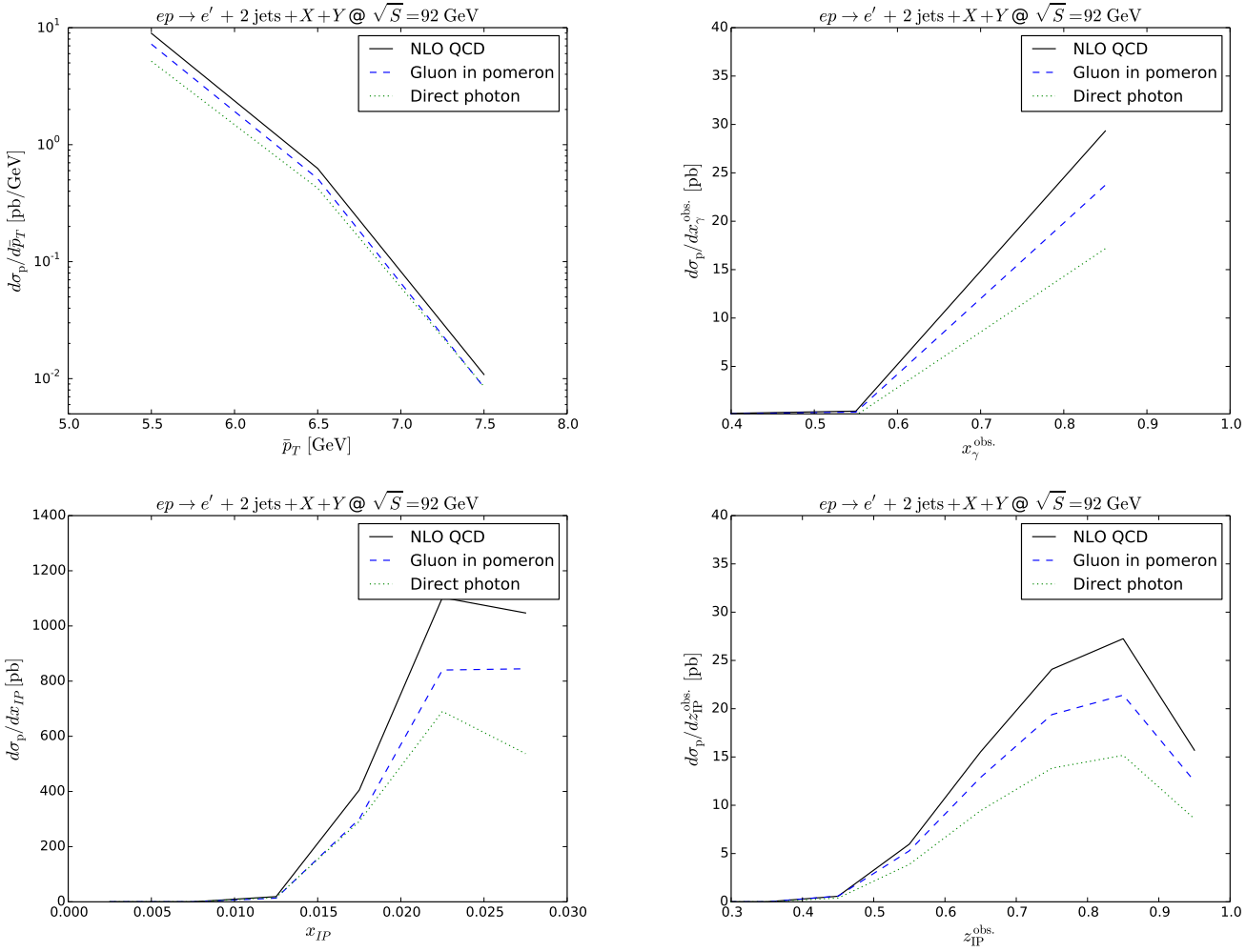
- Improved Weizsäcker-Williams photon spectrum
- Photon PDFs: GRV HO
- Diffractive PDFs: H1 2006 Fit B. To do: Fit A, ZEUS, nDPDFs.
- Scales: $\mu_R = \mu_F = \bar{p}_T$. To do: Factorization breaking.

Important observables:

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

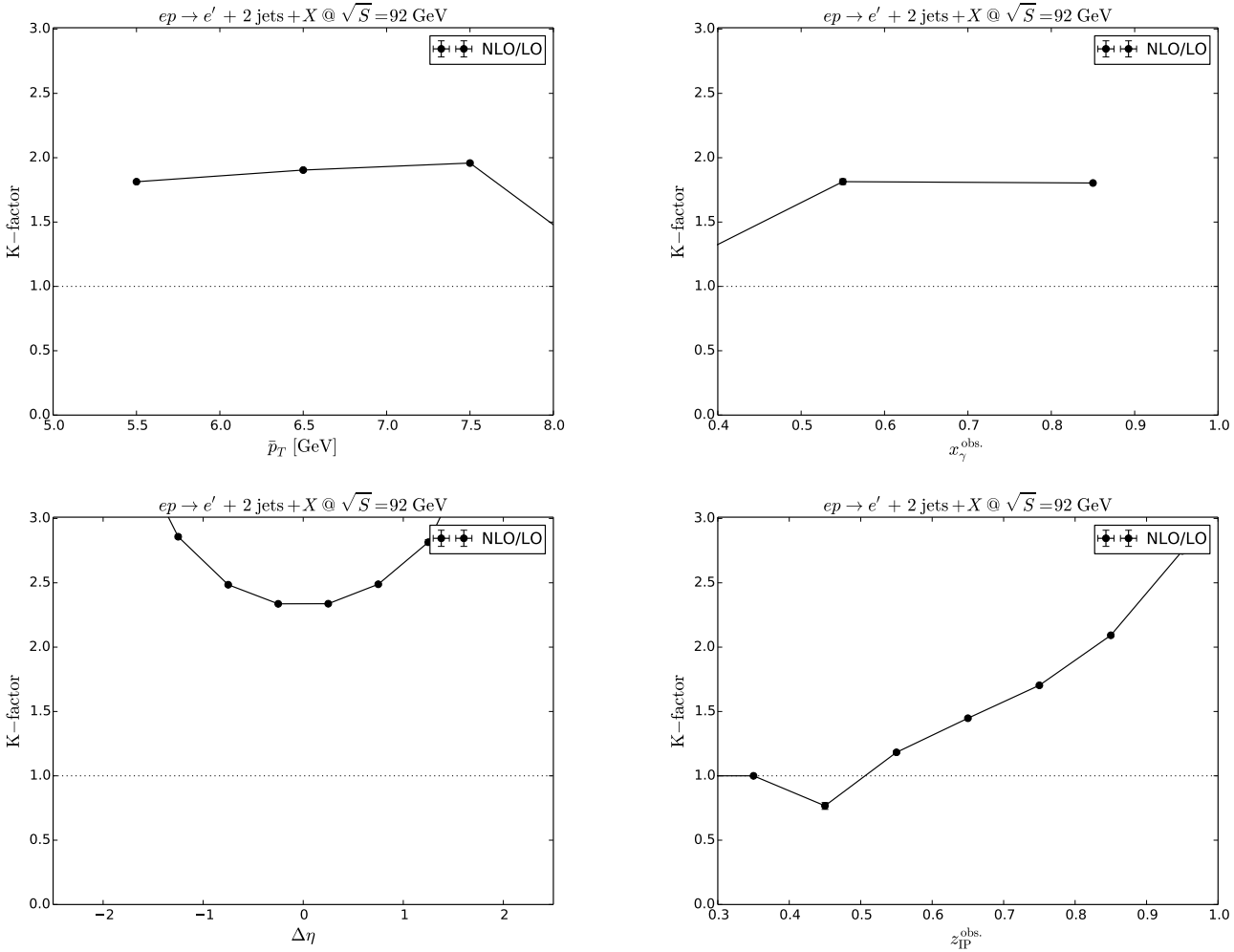
Diffractive photoproduction of dijets at the EIC

V. Guzey, M. Klasen, in preparation



K-factors for diffractive dijet photoproduction

V. Guzey, M. Klasen, in preparation



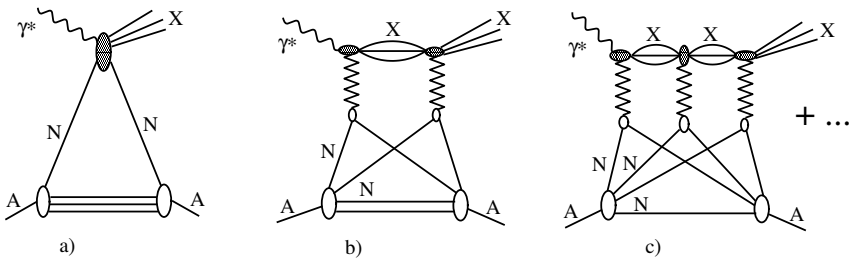
Diffractive PDFs in nuclei

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

Defined similarly to those for nucleons:

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

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



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

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

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

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

Diffractive nuclear PDFs at the LHC

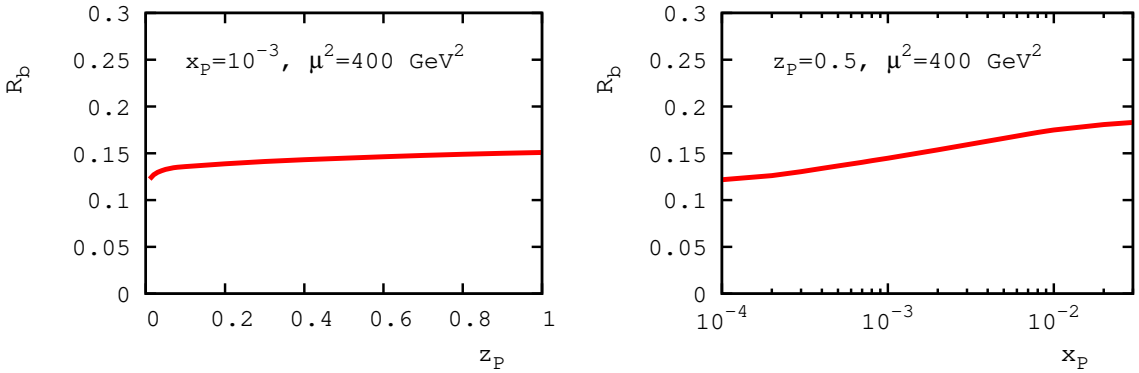
MK, V. Guzey, JHEP 1604 (2016) 158 [1603.06055]

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

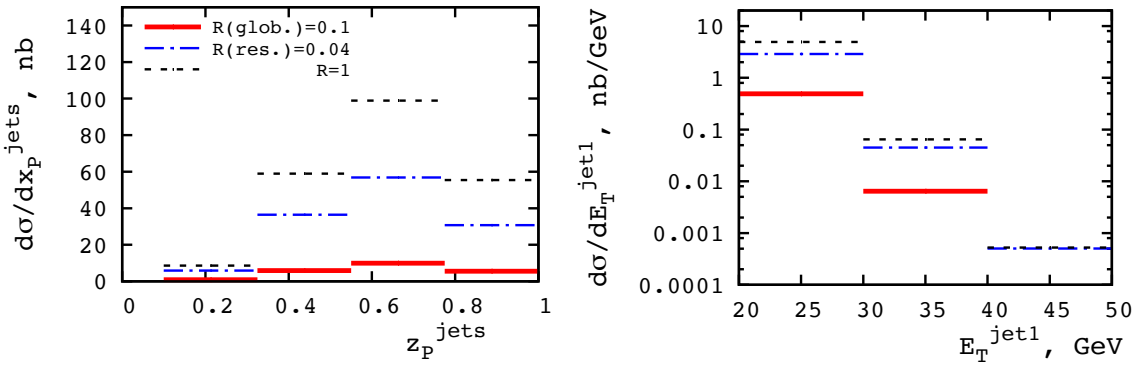
Diffractive nuclear PDFs in the impulse approximation (IA):

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

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:



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