Diffractive PDFs

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1

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Outline:

- Collinear factorization and diffractive PDFs
- Diffractive PDFs from global fits
- Diffractive dijet photoproduction at HERA and factorization breaking
- Nuclear diffractive PDFs in eA diffractive DIS
- Outlook and summary

Diffraction in ep DIS at HERA momentum fraction $\mathbf x$ and $\mathbf x$ and $\mathbf x$ are $\mathbf x$ in the $\mathbf x$ target fragmentation is a second to the second state of the second state \mathbf{r} The typical event with a rapidity \mathbf{r}_1 a diagram shown in !gure 1. An incoming electron or positron *X* is the mass of the diffractive system \overline{X} omme by the diffractive extensive exchange.

• Diffractive scattering at high energies \rightarrow target intact and rapidity gap, i.e., large region in a detector with no activity. a diagram shown in the large than in the set of the position of position of position of position or position o with four-momentum *k* scatters off the incoming proton with energies → target intact and rapidity gap, i.e., large $t = \frac{1}{\sqrt{2}}$ $B_{\rm eff}$ is the momentum fraction carried by the struck parton with σ i in the literature. The two momentum fractions satisfy the con- i the con- i the con-

- Present in both soft [elastic pp scattering] and hard [ep deep inelastic scattering (DIS)] processes. *Y* with four-momentum *p*! . The proton may stay intact or α is can also dissociate into a low mass excited into a low mass excitatio witehing] and hard <u>f</u>ep deep inelastic scatterin α scattering] and hard [en deen inelastic scattering *x* position by an arrange proton carried by the initial proton carried by the initial proton carried by \mathcal{L} momentum fraction carried by the diffractive exchange, and ep inelastic scattering _i
- Challenging in QCD due to enhanced HT/non-linear effects. *Y* and the diffractive system *X*, see the diagram in !gure 1. α is any diffractive event is characterized. the induced the individual proton, i.e. h_i and h_i are h_i and h_i are the events of h_i are characterized by small graduate *xL mean* enects. $\mathbf{1}_{\mathbf{r}}$ straint *x* = ξβ. The variable ξ can be related to the fraction *x*^L
- Classic and most studied example: diffraction in ep DIS at HERA \rightarrow one of main HERA results that diffraction ~10-15% of total DIS cross section. s^2 diffraction in an DIS of $HCDA$, and of main and the diffractive system in \mathcal{O}_ℓ and \mathcal{O}_ℓ and \mathcal{O}_ℓ and \mathcal{O}_ℓ and \mathcal{O}_ℓ and \mathcal{O}_ℓ are as a set in and in \mathcal{O}_ℓ and \mathcal{O}_ℓ and \mathcal{O}_ℓ are as a set in an • Classic and most studied example: diffraction in ep DIS at HERA \rightarrow one of main *^q*² ⁼ [−]*Q*² section can be written in a factorized form HERA results that diffraction ~10-15% of total DIS cross section. the *i.e.* shootman.
ction are characterized by small ξ, or large *x*^L meaning that the

where *t* is the momentum transfer squared at the proton vertex, *M*² **Standard DIS variables:** exchange (often referred to as the Pomeron) between the pro-

$$
q^2 = -Q^2
$$
, $x = \frac{Q^2}{2p \cdot q}$, $W^2 = (p+q)^2$, $y = \frac{p \cdot q}{p \cdot k}$

in the literature. The two momentum fractions satisfy the con-Strain *x* = *καταστοποιησία του του καταστού*. and a metal and a metal diffraction-specific variables: The diffractive cross sections can be expressed by the two

rapidity gap

\n
$$
t = (p - p')^{2}, \quad \xi = \frac{Q^{2} + M_{X}^{2} - t}{Q^{2} + W^{2}}, \quad \beta = \frac{Q^{2}}{Q^{2} + M_{X}^{2} - t},
$$

• Reduced DIS cross section in diffractive scattered proton (or its excitation) *Y* by a rapidity gap. terms of diffractive structure $\sigma_{\text{red}}^{D(4)} = F_2^{D(4)}(\beta, \xi, Q^2, t)$ functions: • Reduced DIS cross section in $P(A) = P(A)$ and $P(A) = P(A)$

S cross section in
ctive structure

$$
\sigma_{\text{red}}^{\text{D}(4)} = F_2^{\text{D}(4)}(\beta, \xi, Q^2, t) - \frac{y^2}{Y_+} F_L^{\text{D}(4)}(\beta, \xi, Q^2, t)
$$

$$
Y_+ = 1 + (1 - y)^2
$$

Collinear factorization in diffractive DIS

- Similarly to inclusive $DIS \rightarrow$ collinear factorization for diffractive DIS, collins, PRD 57 (1998) 3051, PRD 61 (2000) 019902 (erratum).
- Diffractive cross section given by convolution of coefficient functions (same as in inclusive case) with diffractive parton distributions (PDFs):

$$
F_{2/L}^{D(4)}(\beta,\xi,Q^2,t) = \sum_{i} \int_{\beta}^{1} \frac{dz}{z} C_{2/L,i}(\beta/z,Q^2) f_i^D(z,\xi,Q^2,t)
$$

• Similarly to inclusive case, operator definition for diffractive PDFs:

$$
f_i^D(z,\xi,Q^2,t)=\frac{1}{4\pi}\frac{1}{2}\sum_s\int dy^- e^{-izp^+y^-}\sum_{X,s'}\langle p,s|\bar{\psi}(0,y^-,{\bf 0}_T)|p',s';X\rangle\gamma^+\langle p',s';X|\psi(0)|p,s\rangle
$$

• Diffractive PDFs = conditional probabilities of finding partons in the proton, provided that it scatters into the final system Y with momentum p' .

• Similarly to inclusive case, diffractive PDF are universal (probed in inclusive diffraction, diffractive jet production, etc.) and obey Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) evolution equations at fixed ξ and t .

Diffractive PDFs from global fits to include an orbital corresponds to the subset of th **ing term, in a sense of the small group in the small group of the South Way of the South Way of the Pomeron S** \mathbf{S} structure function data. H1 and ZEUS used the following th $\mathbf{F}_{\mathbf{F}}$ macuve ribi s fibili giobal nu Diffractive DDEs frame clabs ratio of the neutron to proton production is equal to two as a

- Diffractive PDFs given by long-distance matrix elements → non-perturbative and need to be extracted from data using global QCD fits. *z f* IP *ⁱ* (*z*, *µ*² 0) = *Aiz* where *i* is a gluon or a light quark. The parameters *C*q, *C*^g were active PDFs given by long-distance matrix elements \rightarrow non-perturbative and *be exiracted from data using global QCD iits.* \mathbf{q} $\overline{}$ as the structure of the Pomeron could *a priori* depend on consequence of the Clebsh–Gordan isospin relations between
- Depend on 4 kinematic variables, c.f. usual PDFs \rightarrow need simplifications. \sim sum of two exchange contributions, IP and IR, each interior \sim allowed to vary and in particular they were allowed to take both α **been internations.**
IRC *die the vanishing* of the vanishing of the an exponential regulating factor of exp(−0*.*01*/*(1 − *z*)) has \cdot D end on 4 kinematic variables, c.f. usual PDFs \rightarrow need s
- Proton vertex (Regge) factorization, Ingelman, Schlein, PLB 152 (1985) 256, for the leading Pomeron and sub-leading (*ξ* ≥ 0.03) Reggeon contributions: vertex (Regge) factorization, li
pand qub logding (*t* > 0.03) D i (*z*) (*z*) i *z*) *f* (*z*) *f* i *f* i *x*) *f* (*z*) *p* ation, Ingelman, Schlein, PLB 152 (1985) 256, for the leading ading (ξ ≥ 0.03) Reggeon contributions: $\mathcal{L}(\mathcal{L}) = \mathcal{L}(\mathcal{L})$ \bullet D \overline{P}_0 on vertex (Reage) factorization, _{Ingelman} schlein PLB 152 (1985) on vertex *(induge)* ractonzation, ingelinal, schlein, PLB 132 (1983)
pron and sub-leading ($\xi > 0.03$) Reggeon contributions: Pomeron implies *f* IP

 $f_i^D(z, \xi, Q^2, t) = f_{I\!\!P}(\xi, t) f_i^{I\!\!P}(z, Q^2) + f_{I\!\!R}(\xi, t) f_i^{I\!\!R}(z, Q^2)$ $\int f(x,t) \, dP(t) \, d^2x + f(t)$ $(z, \zeta, Q, \iota) = J P(\zeta, \iota) J_i$ $(z, Q) + J R(\zeta, \iota)$ been included. (z, Q^2) *f p* \ddot{B} $\ddot{B} = 0.05$ \ddot{B} $\ddot{C} = 0.05$ \ddot{C} $f_i^D(z,\xi,Q^2,t) = f_{I\!\!P}(\xi,t) f_i^{I\!\!P}(z,Q^2) + f_{I\!\!R}(\xi,t) f_i^{I\!\!R}(z,Q^2)$

. The fluxes motivated by Regge theory: \cdot T

$$
f_{\mathbb{P},\mathbb{R}}^p(\xi,t) = A_{\mathbb{P},\mathbb{R}} \frac{e^{B_{\mathbb{P},\mathbb{R}}t}}{\xi^{2\alpha_{\mathbb{P},\mathbb{R}}(t)-1}}, \qquad \alpha_{\mathbb{P},\mathbb{R}}(t) = \alpha_{\mathbb{P},\mathbb{R}}(0) + \alpha'_{\mathbb{P},\mathbb{R}}
$$

• Simple form for sea quark (valence =0) and gluon PDFs of the Pomeron: **S** Cimple form for sea quark (valence -0) and glug **EXAMPLE TO BIP, A SURE YOURTHOUSE A** BIG SIGN \overline{DDE} of the Demeren: nple form for sea quark (valence =0) and gluon PDFs of the Pomeron: We emphasize here that the notions of Pomeron and eron: \bullet (

$$
zf_i^{\mathbb{P}}(z, \mu_0^2) = A_i z^{B_i} (1 - z)^{C_i}
$$

 $\bullet f^{\prime\prime}_u=f^{\prime\prime}_d=f^{\prime\prime}_s$, and massless heavy flavors in the variable flavor scheme familiar from the soft *percentated* through DGLAP evolution. S_{S} speaking the parameterization in the parameterization S_{S} is S_{S} the Registery. Never do in the vanual human summer and the state of the Registery. TUGLAT GVOIUM NUMBERS OF THE REGISTRATION PRODUCTION AT LARGE PRODUCTION AT LARGE PRODUCTION PRODUCTION AT LARGE PRODUCTION AT LARGE PRODUCTION PRODUCTION PRODUCTION AT LARGE PRODUCTION AT LARGE PRODUCTION AT LARGE PRODUCT \mathbf{r} $\overline{}$ ϵ $\frac{J}{R}$ $\bullet f_u^{\text{IP}} = f_d^{\text{IP}} = f_s^{\text{IP}}$, and massless heavy flavors in the variable flavor scheme generated through DGLAP evolution.

 P_{0} both the different of the major DDE_2 $\sum_{i=1}^{n}$ speaking the parameterization in $\sum_{i=1}^{n}$ is $\sum_{i=1}^{n}$ by $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ is $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ in $\sum_{i=1}^{n}$ in the Regge theory. One does not assume anything here about the C and S differ in the form of gluon parameterization at large *z*, $\frac{1}{2}$ COTISTIGHTCU BL $\frac{1}{2}$ or $\frac{1}{2}$ parameters. in addition to inclusive data, diffractive data, diffractive data, diffractive data are inclusive diffractive diffractive data are inclusive diffractive data are inclusive diffractive data are inclusive diffractive diffra p^{σ} $\frac{1}{2}$ canoninonino profine bilar can be better constraints and $\frac{1}{2}$ cannot be better constraints. an exponential regulating factor of exp(−0*.*01*/*(1 − *z*)) has • Reggeon f_i^R taken from pion PDFs \rightarrow can be better constrained at EIC, Armesto, Newman, Slominski, Stasto, PRD 110 (2024) 5, 054039.

 \bullet Most notable examples are ZEUS $_2$ and I analyses of their own data, $_\mathrm{Chekanov \, et \, al.}$ NPB 831 (2010) 1; Aktas et al, EPJC 48 (2006) 715. **lable examples are**
0) 1: Aktas et al EP IC 45 **5**US2and H1 analy
1715 b

 α^2 at parameterisation chosen for the gluon density at the starting scale for α <u>ই⁼শ্রীটাইসিঁএল</u>া\/ constrained at large z - F_{F} and F_{F} of F_{F} is shown is the central result is shown in the central result is shown in the central result is shown in the central resu favor ZEHS C and H1 R fits \sim **b.6 Pressures and outer experimental and outer experimental and the experimental and theories.** retical uncertainties added in quadrature. For 'Fit B', only the total uncertainty is shown. **g zf 2 = 6 GeV ² Q g zf 2 = 20 GeV ² Q ZUSBRE SHIffractive di** - ZEUS DPDF C **g**• Diffradtive gluon Popt^s >> quark PDFS - port odrly constrained at large z → need to includ**e <mark>data හ</mark>ায়**াোঁ bactive d্টুষ্ট্চাs → favor ZEUS C and H1 B fits. **g**

0.4

0.4

Diffractive PDFs from global fits (3) H1 β = 0.8 (l=0) **H1**

 10^{-1}

• Good description of original and more recent H1 data, Aaron et al, EPJC 72 (2912) 2074 \mathbf{Q}^2 [GeV²] **10 ² 10** $\overline{Q^2}$ [\overline{GeV}^2] **10 ² 10 -2 10**

 10^{-1}

• Comparison of LRG with proton-tagged cross section measurement → **~20%** contribution of proton dissociation. The contribution of a_i combination of all data samples. The reduced cross section values are multiplied by a scaling

Diffractive dijet photoproduction

- Collinear fact: same diffractive PDFs for pQCD description of various processes.
- Diffractive dijet electro- and photoproduction in ep scattering \rightarrow constraints on gluon distribution.

• Cross section is known to NLO accuracy Klasen, Kramer, Salesch, Z. Phys. C 68, 113 (1995); Klasen, ences accuracy Niasen, Nianer, Salesch, Z. Frijs. C 66, في Kramer, Z. Phys. C 72, 107 (1996), Z. Phys. C 76, 67 (1997); Klasen, Rev. Mod. Phys. 74, 1221 (2002) factorization of the cross section is known to NI a accuracy Kless + *Kromer Seleceb 7* Phys. C.68, 113 (1005): Klesse

P	β	γ	γ	γ
direct-photon	resolved-photon			
Kramer, Z. Phys. C 72, 107 (1996), Z. Phys. C 76, 67 (1997); Klasen, Rev. Mod. Phys. 74, 1221 (2002)				
$d\sigma = \sum_{a,b} \int dy \int dx \gamma \int dt \int dx p \int dz p f_{\gamma/e}(y) f_{a/\gamma}(x_{\gamma}, M_{\gamma}^2) f_{P/p}(x_{I\!\!P}, t) f_{b/I\!\!P}(z_{I\!\!P}, M_{I\!\!P}^2) d\hat{\sigma}_{ab}^{(n)}$ \n				
Photon flux in Weizsäcker- resolved photon;	Photon; The top of the problem, the problem is given by the formula:			
Without the system of the system, and the system is given by the formula:				
Problem 7	Problem 7			
Problem 8	Problem 8			
Problem 8	Problem 8			
Problem 9	Problem 9			
Problem 9	Example 1			
Problem 9	Example 1			
Problem 9	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 10	Example 1			
Problem 1				

Diffractive dijet photoproduction (2) \overline{Q} 40000

• Universality of diffractive PDFs successfully tested in diffractive dijet and open ε ham produ ε t j n DI ς_{i0} Algas at al. y ½1 Coll.], JHEP 10, 042 (2007); EPJ C 71, 549 (2010); EPJ C 50, 1 (2007); Chekanov et al. [ZEUS Coll.], EPJ C 52, 813 (2007); Chekanov at al. [ZEUS Coll.], NPB 831, 1 (2010) <u>'EU</u> θ .011 θ .015 as at θ .02

• At the same time, NLO pQCD QCD overestimates cross sections of diffractive dijet photoproduction at HERA by **factor 2**→ factorization breaking, Aktas at al. [H1 Coll.], $0.6P$ J 0 7 8 , 549 (2007); Aaron et al. [H1 Coll.], EPJ C 70, 15 (2010); Andreev et al. [H1 Coll.], JHEP 05, 056 (2015); Chel**z**pov at al. [ZEUS Coll.], EPJ C 55, 177 (2008). o chekanov et al. [ZEU
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dijet photoproc $\overline{1}$

Factorization breaking luon breakhl 50

- Mechanism of this factorization breaking remains unknown: anism of this factorization breaking remains unkno ec preaking remains unknown: $\sqrt{2}$
- global suppression factor $R \approx 0.5$ r
|
| 0
|
- suppression of only resolved photon contribution by $R \approx 0.34$ as expected in hadron-hadron scattering, Kaidalov, Khoze, Martin, Ryskin, PLB 567, 61 (2003); Klasen, Kramer, EPJ C 70, 91 (2010) , 11195
. $0.5 \times 1.5 \times 10^{-5}$ $\overline{}$ 0.21 ; Klasen, Kramer, EPJ C 70,
- flavor-dependent combination of these mechanisms, Guzey, Klasen, EPJ C 76, 467 (2016)

Diffraction in DIS on nuclei

- Never been measured at HERA, but will be at the Electron-Ion Collider (EIC). $\sum_{i=1}^{n}$
- Besides accessing nuclear diffractive PDFs for the first time, enhanced sensitivity to non-linear effects, e.g., gluon saturation in heavy nuclei. ra, o.y., gidon salaration in haavy hasia.
- Sensitive observable is the ratio of diffractive to total DIS cross sections for a heavy nucleus and the proton, Accardi et al., EPJ A52 (2016) 9, 268 [1212.1701 [hep-ex]]. i tel DIC exece esctions for c kan Dio cross sculuns for a remained intact and the highly virtual photon fragmented into a final state *X* that was sepratio of diffractive to fotal DIS cro are indicative of a color neutral exchange in the *t*-channel between the virtual photon and \mathbf{r} , Accalul et al., EFJ A32 (2010) 9, 200 [1212.17 *Deep Inelastic Scattering: Kinematics*

Leading twist approach to nuclear shadowing

- \bullet Nuclear shadowing: suppression of nuclear PDFs $f_{i/A}(x,Q^2) / [A f_{i/p}(x,Q^2)] < 1$
- LTA = method to calculate various nuclear parton distributions at small x (usual, generalized, diffractive), Frankfurt, Strikman, EPJ A5 (1999) 293; Frankfurt, Guzey, Strikman, Phys. Rept. 512 (2012) 255 \rightarrow alternative to global fits of PDFs.
- Based on:
	- Gribov-Glauber model of NS for soft hadron-nucleus scattering
	- QCD factorization theorems for inclusive and diffractive DIS.

• $γ^* + A → X + A'$ amplitude is a series of diffractive scattering off $i = 1, 2, ..., A$ target nucleons:

11 γ[∗] γ[∗] γ[∗] *X X X XX X* (*a*) (*b*) (*c*) *N N N N N A A N* " *A A*" *A A*" *IP IP IP IP IP IP σγ***A*→*XA* ⁼ [∫] *^d*² *b*⃗|Γ*γ***A*→*XA*(*b*⃗)| 2 = 4*π dσγ***N*→*XN*(*t* = 0) *dt* [∫] *^d*² *^b*⃗ [∫] *dzρA*(*b*⃗,*z*)*eiz*Δ*γ***Xe*−¹ [−] *ⁱ^η* ² *σ*soft∫ ∞ *z dz*′*ρA*(*b*⃗,*z*′) 2 nuclear density diffractive cross section on proton measured at HERA model-dependent cross section ^l Coherent diffraction *A*′ = *A*:

LTA to nuclear shadowing (2)

• Apply collinear QCD factorization for diffractive DIS, Collins, PRD 57 (1998); PRD 61 (2000) $0.019902 \rightarrow$ from structure function to parton distributions:

$$
f_{i/A}^{D(3)}(x, x_p, Q^2) = 4\pi f_{i/p}^{D(4)}(x, x_p, Q^2, t = 0) \int d^2 \vec{b} \left[\int dz \rho_A(\vec{b}, z) e^{izx_p m_N} e^{-\frac{1 - i\eta}{2} \sigma_{soft}^i(x) \int_z^{\infty} dz' \rho_A(\vec{b}, z')} \right]^2
$$

= $f_{i/p}^{D(3)}(x, x_p, Q^2) \frac{1}{\sigma_{el}^i(x)} \int d^2 \vec{b} \left[1 - e^{-\frac{1 - i\eta}{2} \sigma_{soft}^i(x) T_A(\vec{b})} \right]^2$

$$
\sigma_{el}^i(x) = \frac{[\sigma_{soft}(x)]^2}{16\pi B_{diff}} \left[\frac{\sigma_{el}(x)}{\sigma_{eff}^i(x)} \right]^2
$$

• Transparent interpretation: nuclear diffractive PDFs suppressed (shadowed) in proportion to the nuclear elastic cross section.

• Similarly for quasi-elastic scattering using completeness final states A' :

$$
\sigma_{\gamma^* A \to X A'} = \int d^2 \vec{b} \langle A | \left| \Gamma_{\gamma^* A \to X A} (\vec{b}) \right|^2 |A\rangle = \sigma_{\gamma^* N \to X N} \frac{1}{\sigma_{el}} \int d^2 \vec{b} \left(\left| 1 - e^{-\frac{1 - i\eta}{2} \sigma_{soft} T_A(\vec{b})} \right|^2 + e^{-\sigma_{in} T_A(\vec{b})} - e^{-\sigma_{soft} T_A(\vec{b})} \right)
$$

$$
\tilde{f}_{i/A}^{D(3)}(x, x_{I\!\!P}, Q^2) = f_{i/p}^{D(3)}(x, x_{I\!\!P}, Q^2) \frac{1}{\sigma_{el}^i(x)} \int d^2 \vec{b} \left(\left| 1 - e^{-\frac{1 - i\eta}{2} \sigma_{soft}^i(x) T_A(\vec{b})} \right|^2 + e^{-\sigma_{in}^i(x) T_A(\vec{b})} - e^{-\sigma_{soft}^i(x) T_A(\vec{b})} \right)
$$

$$
\sigma_{in}(x) = \sigma_{soft}(x) - \sigma_{el}(x)
$$

• In this case, NS is given by sum of elastic and inelastic nuclear cross sections.

LTA predictions for nuclear diffractive PDFs

- Assumed that diffractive intermediate states X do not mix \rightarrow one free parameter $\sigma^i_{\text{soft}}(x) \rightarrow$ controls size and uncertainties of LTA predictions.
- High shadowing: given by probability of diffraction $\sigma_{\text{soft}}^i(x) \approx \sigma_2(x) \equiv$ 16*π fi*/*p*(*x*) ∫ 0.1 *x* $dx_{I\!\!P}$ *xIP* $f_{ilp}^{D(4)}(x, x_p, t=0)$
- Low shadowing: calculated using model for hadronic structure of ρ meson.
- In LTA, nuclear shadowing driven by diffraction on proton \rightarrow 10-15% probability of diffraction in DIS@HERA leads to large suppression of nuclear PDFs at small x.
- Compare to impulse approximation (IA): *f D*(3) *i*/*A* $A f_{ilp}^{D(3)}$ *i*/*p* = $4\pi B_\text{diff}$ $\frac{D_{\text{diff}}}{A}$ $\int d^2 \vec{b} \, (T_A(\vec{b}))^2 =$ $B_{\rm diff}$ $\int_{A}^{d} dt F_A^2(t) = 4.3$

LTA predictions for Rdiff/tot

• Suppression $R_{\rm diff/tot} \approx 0.5-1$ (quarks) and $R_{\rm diff/tot} \approx 0.5-1.3$ (gluons) due to interplay of large leading twist nuclear shadowing for diffractive and usual nuclear PDFs.

Outlook: diffraction at EIC

- Several recent global QCD fits for proton diffractive PDFs using all (inclusive+dijets) HERA data, Salajeghen at al., PRD 107 (2024) 9, 093038; PRD 106 (2022) 5, 054012
- \bullet Further progress possible at the Electron-Ion Collider (EIC) $\rightarrow \sqrt{\scriptstyle S_{ep}}\sim 100$ GeV lower than at HERA → constrain sub-leading (Reggeon) contribution at large *ξ*, Armesto, Newman, Slominski, Stasto, PRD 110 (2024) 5, 054039

• Similarly, NLO pQCD predicts 10-35% contribution of sub-leading Reggeon trajectory for $x_P > 0.06$ in diffractive dijet photoprofuction at EIC, Guzey, Klasen, JHEP 05 (2020) 074

Outlook: diffraction in UPC at LHC (2) observation that it is much easier to be nucleus than the proton, see figure 13 and the proton, see figure 13 and the proton, see figure 13 and idiffraction in OPC at LHC (2) *Outlook: diffraction in UPC at LHC (2)* where *TA*(*b*) is the nuclear optical density normalized to the number of nucleons *A* and

· Besides nuclear diffractive PDFs, heavy nucleus can be used to suppress the resolved photon contribution \rightarrow new handle on mechanism of factorization **breaking, Guzey, Klasen, JHEP 04 (2016) 158** $\begin{bmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} \ \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix}$
 $\begin{bmatrix} W,b \end{bmatrix}$
 $\begin{bmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} \ \mathbf{0} & \mathbf{0} \end{bmatrix}$
 $\begin{bmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} \ \mathbf{0} & \mathbf{0} \end{bmatrix}$ **ACU** ر
س ive PDFs, heavy nucleus can be used to suppress the tion \rightarrow new handle on mechanism of factorization relative importance of inelastic nuclear shadowing include in our case is much smaller than that in our case i

 \setminus

• Suppression factor for resolved photon: $R(\text{res.}) = \frac{\int d^2b\,|{\cal A}_{\gamma T\to VT}(W,b)|^2P_{VT}(W,b)}{(W,b)^2}$ $\int d^2b \, |\mathcal{A}_{\gamma T \to VT}(W, b)|^2$ $\text{Capp}(\text{Coulomb} \text{ factor of 10} \text{ vectors of 200}$ the Glauber model of nuclear shadowing for coherent photoproduction of vector mesons on t asolved photop: $R({\rm res}^+) = \frac{\int d^2b\, |{\cal A}_{\gamma T \to VT}(W,b)|^2 P_{VT}(W,b)}{2\pi\,2\,kT}$ $\int d^2b \, |\mathcal{A}_{\gamma T \to VT}(W, b)|^2$

 $\left(1 - e^{-\frac{\sigma_{\rho N}(W)}{2}T_A(b)}\right)$

 $\overline{\mathbf{b}}$ is the probability to not have the strong inequality to not have the strong inequality $\overline{\mathbf{b}}$ excessive and interaction at the impact parameter \downarrow Probability to not have

$$
P_{VA}(W,b) = e^{-\sigma_{\rho N}(W)T_A(b)}
$$

· Suppression factor: proton vs. nucleus

 f_V

in Glauber model

Numerical in the view of the high-

 $\mathcal{A}_{\gamma A\to VA}(W,b)=\frac{e}{f_{\rm B}}$

Outlook: diffraction in UPC at LHC (3)

- \bullet It is much easier to break up nucleus and fill the rapidity gap \rightarrow $R({\rm res})_{\rm A}$ \ll ${\rm R({\rm res})}_{\rm p}$
- NLO pQCD predictions for diffractive dijet photoproduction in Pb-Pb UPCs at LHC, Guzey, Klasen, JHEP 04 (2016) 158

Summary

- Diffractive PDFs is a standard tool of perturbative QCD.
- In the proton case, they are extracted using global fits to HERA data.
- Further progress at EIC for the sub-leading contribution for large ξ .
- In the nuclear case, diffractive PDFs never been measured \rightarrow will be at EIC and can be in Pb-Pb UPCs at LHC.
- Open question: mechanism of factorization breaking in diffractive dijet photoproduction \rightarrow can be addressed in UPCs at LHC.
- Diffraction in ep and eA can be alternatively addressed in the dipole model, where the emphasis on the gluon saturation.