

Small x and diffraction at the EIC

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Small x and diffraction at the EIC, INT Program on Heavy Ion Physics in the EIC era, Seattle, August 19, 2024 $Small$ x and dit

Outline

• Small x

- EIC kinematics. Evolution equations DGLAP vs BFKL
- Resummation at small x
- Nonlinear evolution: parton saturation. Opportunities at EIC

- **• Inclusive diffraction at EIC**
	- Longitudinal diffractive structure function
	- Extraction of Pomeron and Reggeon, estimate of uncertainties

What is EIC ?

EIC: **E**lectron-**I**on **C**ollider facility that will be built at Brookhaven National Laboratory using and upgrading existing RHIC complex. Partnership between BNL and Jefferson Lab.

Capabilities of EIC

High luminosity 1033 − 1034*cm*−² *s*−¹ (100-1000 times more than HERA)

Variable center of mass energies 20 -140 GeV

Beams with different A: from **light nuclei (proton)** to the **heaviest nuclei (uranium)**

Polarized electron and proton beams. Possibility of polarized light ions.

Dedicated forward instrumentation: proton tagging (essential for diffraction)

Up to two interaction regions

Kinematic range at EIC

Proton. Lie Knichland lange over Nucleus: EIC the only DIS machi redictes. Little the only Distination to extend down to sinality nuclear targets, and by dijet, electro-weak boson and D-meson ps with HERA, extends to larger x μ . EIC the only DIS machine to ext **istimate the complete luminosity (**∞0.5 fb−1 periodic control production in pPb collisions at the LHC. **Proton**: EIC kinematic range overlaps with HERA, extends to larger x **Nucleus**: EIC the only DIS machine to extend down to small x

proton) equal to 1.

density in a proton bound inside a nucleus to the anucleus to the anual proton bound inside a nucleus to the a
The anual proton bound in a free anual proton bound in a free anual proton bound in a free anual proton bound

Gluon density in proton and nuclei

EPPS21

Collinear limit and DGLAP evolution

Focusing on gluon emissions

 $Q^2 \rightarrow \infty$ Large parameter

Probing small distances

Strong ordering in transverse momenta

 $Q^2 \gg k_{1\perp}^2 \gg k_{2\perp}^2 \gg k_{3\perp}^2 \cdots \gg k_{n\perp}^2$

Collinear dynamics

Resummation of large logarithms

 \int^{Q^2} μ_0^2 dk_1^2 $\frac{1\perp}{}$ k_1^2 $1\perp$ g^2 $\int_{}^{k_{1\perp}^2}$ μ_0^2 dk_2^2 $\frac{2\perp}{\cdot}$ k_2^2 $2\perp$ g^2 $\int_{}^{k_{2}^{2}}$ μ_0^2 dk_3^2 $\frac{3\perp}{ }$ k_3^2 $3\perp$ $g^2\cdots \int _2 ^{k_n^2}$ $n-1\perp$ μ_0^2 dk_n^2 *n*? k_n^2 $n\perp$ $g^2\simeq$ $\int g^2 \log \frac{Q^2}{2}$ μ_0^2 \setminus^n

> $\alpha_s =$ g^2 4π

DGLAP evolution

Dokshitzer-Gribov-Lipatov-Altarelli-Parisi

DGLAP evolution equations for parton densities $\int q_i(x,\mu^2)$ ◆ \int_0^1 $\left(P_{q_i q_j}(z, \alpha_s) \right) P_{q_i g}(z, \alpha_s)$ $\left(q_j(\frac{x}{z}, \mu^2) \right)$ ◆ $\mu^2 \frac{\partial}{\partial \theta}$ *dz* $=$ \sum $g(x,\mu^2)$ $g(\frac{\widetilde{x}}{z},\mu^2)$ $k_{n\perp}$ $P_{gq_j}(z,\alpha_s)$ *P_{gg}*(*z*, α_s) $\partial\mu^2$ *z x j* 00000000 $k_{n-1\perp}$ q_i : quark density, g : gluon density **COOCCOOO Splitting functions** calculated perturbatively *s* $P_{ab}(z, \alpha_s) \equiv P_{b \to a}(z, \alpha_s) = \frac{\alpha_s}{2\pi}$ $P_{ab}^{(0)}(z) + (\frac{\alpha_s}{2\pi i}$ $\int_{a}^{2} P_{ab}^{(1)}(z) + \left(\frac{\alpha_s}{2\pi}\right)$ $\big)^{3}P_{ab}^{(2)}(z)+\ldots$ 2π 2π 2π k_3 LO NLO NNLO Leading order splitting functions $k_{2\perp}$ $\frac{1+z^2}{\sqrt{1+z^2}}$ 3 $\delta(1-z)$ $P_{qq}^{(0)}(z)=C_F$ $+$ $(1 - z)_{+}$ 2 Q^2 $P_{qg}^{(0)}(z) = T_R[z^2 + (1-z)^2]$ dominant at small $z(x)$ $\int \frac{z^2 + (1 - z)^2}{z}$ $\overline{}$ $P_{gq}^{(0)}(z)=C_F$ *z* \sqrt{z} $+\frac{1-z}{\sqrt{2}}$ $\frac{11C_A - 4n_fT_R}{2}$ $\overline{}$ $P_{gg}^{(0)}(z)=2C_{A}% ^{(0)}(z)\equiv2C_{A}^{(0)}(z)\equiv2C_{A}^{(0)}(z)$ $+ z(1-z) + \delta(1-z)$ $(1 - z)_{+}$ *z* 6

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Impact of EIC on collinear PDFs

The lowest x and α and α

Armesto, Cridge, Giuli, Harland-Lang, Newman, effection in the collinear gluon distribution of the collins of the collins of the collins of the collins of t **Schmookler, Thorne, Wichmann** FIG. 10. As for Fig. 9, but for the sea up quark density.

The potential impact on $\mathcal{D}_\mathcal{D}$

ribibli . Combining films and lit. Lit impact i improved precision at large \mathbf{r} . most strongly strongly changes in the scaling violations of the scaling violations of the scaling violations o neutral current curren \blacksquare Nucleus FIC has lar where the EIC pressure $\begin{array}{ccc\end{array}$ lence distribution (smallei $\mathbf x$ better description in the small-x region without $\mathbf x$ impact at emall y for all c impact at small x for all ut also moderate and small $\;$ **Proton** : Combining HERA and EIC. EIC impact mostly <mark>large</mark> but also moderate and small nhal analyses like MSHT20) x. Biggest changes in valence distribution (smaller impact on global analyses like MSHT20) ratio of projected gluon densities in gold and in the proton. The **Nucleus: EIC has large impact at small x for all parton species** from a global fit \mathbb{P}^1 and \mathbb{P}^1 and \mathbb{P}^1 and \mathbb{P}^1 and \mathbb{P}^1 and \mathbb{P}^1

on firm grounds for the first time. The first time α

High energy / Regge / small Bjorken x limit

Large parameter

 $s \to \infty$ $s \gg Q^2 \gg \Lambda^2$ Q^2 fixed, perturbative **Strong ordering in longitudinal momenta** $x \ll x_1 \ll x_2 \ll \cdots \ll x_n$ $p^{+} = p^{0} + p^{z}$ $k_{i}^{+} = x_{i}p^{+}$ Light cone proton momentum $\bar{\alpha}_s \ll 1$ $\ln \frac{1}{x}$ $\simeq \ln \frac{s}{\Omega}$ $\frac{\varepsilon}{Q^2} \gg 1$ Perturbative coupling but large logarithm

$$
\frac{\alpha_s N_c}{\pi} \int_x^1 \frac{dz}{z} = \frac{\alpha_s N_c}{\pi} \ln \frac{1}{x} = \bar{\alpha}_s \ln \frac{1}{x}
$$

Large logarithms **Leading logarithmic LL** resummation

$$
\left(\bar{\alpha}_s \ln \frac{1}{x}\right)^n \qquad \left(\bar{\alpha}_s \ln \frac{s}{s_0}\right)^n
$$

High energy or Regge limit

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High energy / Regge / small Bjorken x limit

compare with DGLAPcollinear approach

Resummation performed by BFKL evolution equation

Balitskii, Fadin, Kuraev, Lipatov

$$
\frac{\partial}{\partial \ln 1/x} f_g(x, \mathbf{k}) = \int d^2 \mathbf{k}' K(\alpha_s, \mathbf{k}, \mathbf{k}') f_g(x, \mathbf{k}')
$$

 $K(\alpha_s, \mathbf{k}, \mathbf{k}') = \alpha_s K_0(\mathbf{k}, \mathbf{k}') + \alpha_s^2 K_1(\mathbf{k}, \mathbf{k}') + \mathcal{O}(\alpha_s^3)$ Branching kernel (perturbative expansion)

QCD: LL, NLL sYM: LL, NLL, NNLL

unintegrated (transverse momentum dependent) gluon density

$$
f_g(x,\bm{k})
$$

$$
\frac{\partial f_i(x, Q^2)}{\partial \log(Q^2)} = \sum_j \int_x^1 \frac{dz}{z} P_{j \to i}(z) f_j(\frac{x}{z}, Q^2)
$$

 $f_i(x, Q^2)$ **integrated (collinear)** parton distribution function (PDF)

BFKL at NLL

$$
\frac{\partial}{\partial \ln 1/x} f_g(x, \mathbf{k}) = \int d^2 \mathbf{k}' K(\alpha_s, \mathbf{k}, \mathbf{k}') f_g(x, \mathbf{k}')
$$

NLL corrections to BFKL $K = \alpha_s K_0 + \alpha_s^2 K_1 + \ldots$

Fadin, Lipatov Camici, Ciafaloni

$$
\omega_P \simeq \overline{\alpha}_s 4 \ln 2(1 - 6.5 \overline{\alpha}_s)
$$

$$
\overline{\alpha}_s = \frac{\alpha_s N_c}{\pi}
$$

NLL corrections to BFKL equation are **large** and **negative**

• running coupling

Main sources:

- **• kinematical effects**
- **• DGLAP anomalous dimension**

Need resummation at small x !

Ciafaloni, Colferai, Salam, AS Altarelli, Ball, Forte; Thorne, White; Sabio Vera

Resummation at small x

Ciafaloni, Colferai, Salam, AS

- Include **kinematical constraint: limits on transverse momenta, resum double transverse logarithms**
- Include DGLAP **splitting function** and **running coupling** in the leading part
- **S**ubtractions to avoid double counting, guarantee **momentum sum** rule
- The *integro-differential* equation becomes double integral equation
- **Transverse** and **longitudinal** momenta no longer factorized

result for the unit calculation. The calculation is done in the fixed coupling case. The fixed coupling case of the fixed coupling case. The fixed coupling case of the fixed coupling case. The fixed coupling case. The fixe **Resummation stabilizes the BFKL expansion**

Intercept, and therefore the resulting growth with $1/x$ is slowed down result and the state of the state predictions even in the predictions of α and α as we see from the set of α prothe cheets. The changes of results of results with P_{I} in significantly More consistent with phenomenology change at $\mathbf x$ 0.35. In Fig. 20.35. we show the effective kernel eigenvalue as a function of μ function of μ function of μ Strong preasymptotic effects. Need DGLAP terms with BFKL

Resummation at small x : phenomenology

Example : structure functions at HERA

- Application of the CCSS resummation to phenomenology of deep inelastic scattering as a function of *x* for fixed values of *Q*² = ² (*x, Q*2) as a function of *x* for fixed values of
- ^{*r*} good simultaneous description of F_{2} \overline{a} between \overline{b} • Very good simultaneous description of F_2, F_2^c at small x

Evidence for BFKL at HERA ?

Ball,Bertoni,Bonvini,Marzani,Rojo,Rottoli

- Used small x resummation method of *Altarelli, Ball, Forte*
- \mathcal{L} respectively. • Perform fits to data with the **cut** on small *x*/small *Q* region
- Observe the variation or lack of variation in χ^2

NNPDF3.1sx, HERA NC inclusive data

- χ^2 changes for DGLAP at NNLO at low x
- **NNLO+NNLLx** gives **best** description
- Interestingly NLO and NLO+NLLx do not differ by a lot (flat splitting function at NLO?)
- **• Resummation important for consistent description from large to small x**

Another small x problem: saturation small x problem: s

3 **Nuclei provide enhancement of the density : opportunities to test saturation at EIC**

sturetian thraugh inglusive structure functions Testing saturation through inclusive structure functions at EIC nearly equal in both frameworks. In the higher-*x* region the BK equation predicts a stronger *Q*² dependence than the DGLAP equation, while in the *x* . 10⁴ region the

Matching of both approaches in the region where saturation effects expected to be small
Ouantify differences away from the matching region: differences in evolution dynamics Quantify differences away from the matching region: **differences in evolution dynamics** Study differences in evolution between **linear DGLAP** evolution and **nonlinear** evolution with **saturation** Next we study how the di⊄erences in the di⊄erences in the di⊄erences in the BK vs. The di⊄erences in the BK vs.
The BK vs. Dividend the BK vs In evolution between linear DGLAP evolution and **nonlinear** evolution **v** aturation

(a) \overline{P} \overline{P} (b) \overline{P} (f) \overline{P} (f) \overline{P} \overline{P} (f) \overline{P} \overline{P} Heavy nucleus: difference between DGLAP and nonlinear are few % for F_2^A and up to 20% for F_L^A .

²*,L ^F* Rew ²*,L*)*/F* BK ²*,L* between the BK structure functions and the matched *F*² (a) and *F*^L (b) for Longitudinal structure function can provide good sensitivity at EIC

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Diffraction at EIC

• Simulations of $F_I^{D(3)}$ for EIC *L*

• Motivation: why is $F_L^{D(3)}$ interesting ? H1 measurement

• Pseudodata simulation, energy beam scenarios. Extraction of $F_L^{D(3)}$

•4D diffractive cross section and Reggeon extraction at EIC

- EIC pseudodata for 4D diffractive cross section with t dependence
- Extraction of Pomeron and Reggeon partonic structure, estimate of uncertainties

Series of works on diffraction at ep/eA machines:

Armesto, Newman, Słomiński, Staśto

Diffraction in DIS

- Diffractive characterized by the **rapidity gap**: no activity in part of the detector gap: no activity in part of the detector one photon exchange approximation, neglecting radiative corrections whose contribution can be
- \bullet At HERA in electron-proton collisions: about 10% events diffractive *POUL IV/0* CVCIILS UIIII ACLIVE
- \bullet Interpretation of diffraction : need colorless exchange refer generally as 'di↵ractive exchange'.

2.1 Di**quariables and definitions** and definitions and definitions and definitions and definitions and definitio

Questions:

- What is the nature of this exchange ? Partonic composition ?
- One, two, or more exchanges ? Pomeron \mathbb{P} , Reggeon \mathbb{R} ?
- Evolution ? Relation to saturation, higher twists ?
- Energy, momentum transfer dependence ?

Diffractive kinematics in DIS one photon exchange approximation, neglecting $\mathbf r$ corrected. For an electron or positron with four momentum *l* and a proton with four-momentum

in Fig. 1, is the presence of the rapidity gap between the final proton (or its dissociated state) $\frac{1}{2}$

Standard DIS variables:

electron-proton cms energy squared:

$$
s = (l + P)^2
$$

photon-proton cms energy squared:

$$
W^2 = (q+P)^2
$$

inelasticity

$$
y = \frac{P \cdot q}{P \cdot l}
$$

Bjorken x

$$
x = \frac{Q^2}{2P \cdot q} = \frac{Q^2}{ys} = \frac{Q^2}{Q^2 + W^2}
$$

 $Q^2 = -q^2$ (minus) photon virtuality

Diffractive DIS variables:

=

 Q^2

 $Q^2 + M_X^2 - t$

$$
\xi = x_{IP} = \frac{x}{\beta} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}
$$

momentum fraction of the Pomeron w.r.t hadron

momentum fraction of parton w.r.t Pomeron

4-momentum transfer squared

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 $t = (P' - P)^2$

 Q^2

 $2(P-P')\cdot q$

 $\beta=$

Diffractive cross section, structure functions where *^Y*⁺ = 1 + (1 *^y*)2. It is also customary to perform an integration over *^t*, defining *d*3^D 2⇡↵²

Diffractive cross section depends on $\bf{4}$ variables (ξ, β, Q^2, t) : $\overline{|\cdot|}$ em $\overline{4 \text{ variables } (\xi, \beta, \zeta)}$ $\frac{1}{2}, \beta, Q^2, t$:

$$
\frac{d^4\sigma^D}{d\xi d\beta dQ^2 dt} = \frac{2\pi\alpha_{\text{em}}^2}{\beta Q^4} Y_+ \sigma_r^{D(4)}(\xi, \beta, Q^2, t)
$$

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

Reduced cross section depends on two **structure functions:** D(4) red ⁼ *^F* D(4) ² (*,* ⇠*, Q*2*, t*) *^y*²

s section depends on two **structure functions:**
\n
$$
\sigma_{\rm r}^{\rm D(4)}(\xi,\beta,Q^2,t) = F_2^{\rm D(4)}(\xi,\beta,Q^2,t) - \frac{y^2}{Y_+} F_L^{\rm D(4)}(\xi,\beta,Q^2,t)
$$

Upon integration over *t*:
 $F^{D(3)}(c, \beta)$

When $y \ll 1$

Upon integration over t:
\n
$$
F_{2,L}^{D(3)}(\xi, \beta, Q^2) = \int_{-\infty}^{0} dt \, F_{2,L}^{D(4)}(\xi, \beta, Q^2, t)
$$
\n
$$
\sigma_r^{D(3)}(\xi, \beta, Q^2) = F_2^{D(3)}(\xi, \beta, Q^2) - \frac{y^2}{Y_+} F_L^{D(3)}(\xi, \beta, Q^2)
$$
\nUnhence, the equations are given by the equations:

\n
$$
F_{2,L}^{D(4)}(\xi, \beta, Q^2) = F_2^{D(4)}(\xi, \beta, Q^2) - \frac{y^2}{Y_+} F_L^{D(3)}(\xi, \beta, Q^2)
$$

Dimensions:

When
$$
y \ll 1
$$

\n
$$
\sigma_r^{D(4,3)} \simeq F_2^{D(4,3)} \qquad \qquad [\sigma_r^{D(4)}] = \text{GeV}^{-2}
$$
\n
$$
\sigma_r^{D(3)} \qquad \text{Dimensionless}
$$

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Phase space (x,Q2) EIC-HERA

EIC 3 scenarios - HERA

EIC can operate at various energy combinations

Can cover wide range of x

Large instantaneous luminosity

Statistics should not be a limiting factor

Why FL D(3) is interesting? FL D(3) at HERA

Why F_L^D *is interesting?*

 F_L^D vanishes in the parton model, similarly to inclusive case Gets non-vanishing contributions in QCD As in inclusive case, particularly sensitive to the diffractive **gluon density** Expected large **higher twists**, provides test of the **non-linear, saturation phenomena**

Experimentally challenging…

Measurement requires several beam energies

 F_L^D strongest when $y \to 1$. Low electron energies

H1 measurement: 4 energies, E_p =920, 820, 575, 460 GeV, electron beam E_e =27.6 GeV

Large errors, limited by statistics at HERA

Careful evaluation of systematics. Best precision 4%, with uncorrelated sources as low as 2%

FL D(3) at HERA 2 DIVI **xIP = 0.0005**

-0.01

) 2 , Q

D

x

-1 4×**10 -1 5**×**10 1**

H1 data

H1 2006 DPDF Fit B

0.03

 Ω^2 ≤ 44.0 $\leq \frac{1}{2}$ **xIP = 0.003**

0.04

H1 conclusions:

Measurements of σ^D consistent with $\mathcal{L}^{\mathbf{a}}$ $\sum_{\alpha=1}^{\infty}$ predictions from the models Measurements of $\sigma_{\rm r}^D$ consistent with

Extracted F_L^D has a tendency to be higher with model predictions within errors than the predictions, though compatible

Overall: $0 < F_L^D < F_2^D$

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(x_le **D** n
5 구
- T

-1 10 1

Pseudodata generation: collinear factorization for diffraction that the di⊄ractive cross sections sections sections or structure functions or structure functions depend on. N
The discussions depend on the discussion of the discussion of the discussion of the discussion of the discussi

Use the collinear factorization for the description of HERA and pseudodata simulation

- •Diffractive cross section can be factorized into the convolution of the perturbatively calculable partonic cross sections and diffractive parton distributions (DPDFs) \mathcal{R} range in the method to obtain the method to obtain the projected pseudodata with errors \mathcal{R} \bullet Dimacrive cross section can be factorized module convolution of the potential for constraining \sim where the sum is performed over all parton flavors (gluon, *d*-quark, *u*-quark, etc.). In
- · Partonic cross sections are the same as in the inclusive DIS
- •The DPDFs are non-perturbative objects, but evolved perturbatively with **DGLAP** 1.0 21 DI 8 are non pertangance objecto, e • The DPDFs are non-perturbative objects, but evolved perturbatively with DGLAP

Pseudodata generation: model for diffractive structure functions 148 3.1 Di 148 3.1 Di 148 149 The fits to the dividence structure structure in the performed by H1 μ 149 The fits to the di 149 structure functions were performed by H1 α and ZEUs α ration: model for diffractive structure functions and the political model, which is a two constant model. The 148 3.1 Dia and HERA data in the State Policy of the State Policy of the State Policy of the State Policy of the
Dia and HERA data in the State Policy of the State Policy of the State Policy of the State Policy of the Sta 1 Jeannad Aellerachn: Monet In Alliactive Structure in model fer diffreetive structure functions PSeudodata generation: model for diπractive structure functions ¹⁵⁵ with given values ⇠*, t* couples to the proton. They are parametrized using the form motivated *eBIP ,IR^t*

- Parametrization of the DPDFs as in H1 and ZEUS analysis $\overline{\hspace{1cm}150}$ become trization of the DPDFs as in H1 and ZEUS analysis $\overline{\hspace{1cm}k}$ *f* D(4) • Parametrization of the DPDFs */ <i>PDFs as in H1 and ZEUS*
- **Regge factorization** assumed
	- \cdot (B(or z) Ω^2) dependence in parton distribution of diffractive exchange factorized from flux factors with (t, ξ) dependence • $(\beta(\text{or } z), Q^2)$ dependence in parton distribution of diffractive exchange β (β) *ⁱ* (*z,Q*2) *.* (9) tactorized from flux fact
-
	- Dominant term 'Pomeron', at low ξ
- At higher ξ additional exchanges 'Reggeons' need to be included
 \overrightarrow{p} \overrightarrow{p} $\overrightarrow{(t)}$ \overrightarrow{p} $\overrightarrow{(t)}$ \overrightarrow{p}

$$
f_i^{D(4)}(z,\xi,Q^2,t) = f_{IP}^p(\xi,t) f_i^{IP}(z,Q^2) + f_{IR}^p(\xi,t) f_i^{IR}(z,Q^2)
$$

Regge type flux:
Trajectory:

$$
P_{E} = t
$$

 152 For the find these terms vertex factorization is assumed, meaning that the diagnosis 10^{10} Regge type flux: Trajectory:

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

¹⁵⁶ by Regge theory For t-integrated case $I(x; \theta)$. Integrated flux: For t-integrated case

 \mathbb{S}_{μ} , μ _k(\mathbb{S}_{μ}) we summarize our findings in Sec. 6.

 I^{I} , I^{I}

$$
\xi^{\text{2C}} \mathbb{P}, \mathbb{R}^{(v)} = 1
$$

*I*rajectory:

For t-Integrate
\n
$$
f_i^{D(3)}(z,\xi,Q^2) = \phi_{IP}^p(\xi) f_i^{IP}(z,Q^2) + \phi_{IR}^p(\xi) f_i^{IR}(z,Q^2)
$$
 \nIntegrated flux: $\phi_{IP,IR}^p(\xi) = \int dt f_{IP,IR}^p(\xi,t)$

Pomeron PDFs obtained via NLO DGLAP evolution starting at initial scale $\mu_0^2 = 1.8$ GeV² Pomeron PDFs obtained via NLO DGLAP evolution starting at initial scale $\mu_0^2 = 1.8$ GeV²
 $\chi^2 f_i(z, \mu_0^2) = A_i z^{B_i} (1 - z)^{C_i}$ $i = a, g$ $P₆$ $\mu_0 = 1.0 \text{ GeV}$

$$
zf_i(z,\mu_0^2)=A_iz^{B_i}(1-z)^{C_i}\qquad \qquad i= q,g
$$

*f*rom the GRV fits to the pion structure function (could also be determined at EIC *n* PDFs taken from the GRV fits to the pion structure function (could also be a

<u>dependence</u> Reggeon PDFs taken from the GRV fits to the pion structure function (could also be determined at EIC!) ⁹⁸ variables for an such event include the standard deep inelastic variables *^Q*² ⁼ *q*² *, x* ⁼ *q*² *, y* ⁼ *^p · ^q* Reggeon PDFs taken from the GRV fits to the pion structure function (*could also be determined at EIC!*)

 $\log\frac{1}{3}$.

Pseudodata generation: energy choice We shall first descript the pseudodata generation: ϵ one momentum transfer momentum transfer momentum transfer the integrated over integrated over in this analysis. Let us rewrite Eq. (5) as \sim Desudodata generation energy shaies. *t* is integrated over in this analysis. Let us rewrite Eq. (5) as T beam energies combine to give 17 distinct centre-of-mass energies (there is a degeneracy T

$$
\sigma_{\text{red}}^{\text{D(3)}} = F_2^{\text{D(3)}}(\beta, \xi, Q^2) - Y_{\text{L}} F_{\text{L}}^{\text{D(3)}}(\beta, \xi, Q^2) \qquad \text{Integrated over t-momentum transfer}
$$

$$
Y_{\text{L}} = \frac{y^2}{Y_+} = \frac{y^2}{1 + (1 - y)^2}
$$

Can disentangle $F_2^{D(3)}$ from $F_1^{D(3)}$ by varying energy and performing the linea $\overline{a^2}$ $\overline{a^2}$ $\overline{a^2}$ $D(2)$ Can disentangle $F_2^{\nu(3)}$ from $F_L^{\nu(3)}$ by varying energy and performing Can disentangle $F_2^{D(3)}$ from $F_L^{D(3)}$ by varying energy and performing the linear fit in Y_L .

$$
y = \frac{Q^2}{xs} = \frac{Q^2}{\beta \xi s}
$$
 Need to vary the energy \sqrt{s} to change y for fixed (β, ξ, Q^2)

EIC energies for electron and proton:

 $E_e = 5,10,18$ GeV

$$
E_p = 41,100,120,165,180,275 \text{ GeV}
$$

in this choice since two combinations 10 Վead to the same combinations 10 Վead to the same centre-of-mass cent
This capacity is the same centre-of-mass centre-of-mass centre-of-mass centre-of-mass centre-of-mass centre-of

- S-17 all 17 combinations
- $5-5$ $5-5$ Dold red S-9 **9 - bold red**

which are added to improve the constraints on the di⊄ractive gluon distribution on the di⊥ractive gluon distrib
The distribution of the distribution distribution. The distribution of the distribution of the distribution o

 \overline{C} and \overline{C} is the distribution of the evaluation is the evaluation is the cross section is the cross sect S-5 5 - green (EIC preferred)

Simulated measurement of FL D(3) vs β in bins of (ξ,Q2)

Uncorr. systematic error 1%, 5 MC samples to illustrate fluctuations

Small differences between S-17 and S-9, small reduction to range and increase in uncertainties. More pronounced reduction in range and higher uncertainties in S-5.

An extraction of F_L^D possible with EIC-favored set of energy combinations

Diffraction at HERA: importance of 'Reggeon'

 $\xi \sigma_r^{D(4)} \simeq \xi F_2^{D(4)}$ vs ξ for fixed $|t| = 0.25 \,\text{GeV}^2$ in bins of β , Q^2

Described by two contributions:

Leading 'Pomeron' at low *ξ*

ξf IP ∼ *ξ*−0.22

Subleading 'Reggeon' at high *ξ*

ξf IR ∼ *ξ*1.0

Subleading terms poorly constrained

EIC pseudodata generation with t dependence

Use ZEUS $I\!P$ + $I\!R$ fit with the GRV pion structure function for the $I\!R$ Pseudodata generated in all 4-variables : ($\beta = z, \xi, Q^2, t$)

Diffractive PDF:

$$
f_k^{D(4)}(z, Q^2, \xi, t) = \phi_{I\!\!P}(\xi, t) f_k^{I\!\!P}(z, Q^2) + \phi_{I\!\!R}(\xi, t) f_k^{I\!\!R}(z, Q^2)
$$

Fluxes:
\n
$$
\phi_{\mathbb{M}}(\xi,t) = \frac{e^{B_{\mathbb{M}}t}}{\xi^{2\alpha_{\mathbb{M}}(t)-1}}
$$
\nTrajectories:
\n
$$
\alpha_{\mathbb{M}}(t) = \alpha_{\mathbb{M}}(0) + \alpha'_{\mathbb{M}}t \qquad \mathbb{M} = \mathbb{P}, \mathbb{R}
$$

Reduced cross section:

$$
\sigma_{\text{red}}^{D(4)} = \phi_{I\!\!P}(\xi, t) \mathcal{F}_{2}^{I\!\!P}(\beta, Q^2) + \phi_{I\!\!R}(\xi, t) \mathcal{F}_{2}^{I\!\!R}(\beta, Q^2) \n- \frac{y^2}{Y_+} \left[\phi_{I\!\!P}(\xi, t) \mathcal{F}_{L}^{I\!\!P}(\beta, Q^2) + \phi_{I\!\!R}(\xi, t) \mathcal{F}_{L}^{I\!\!R}(\beta, Q^2) \right]
$$

Flux parameters: $\xi \phi_{I\!\!P}(\xi, t) \propto \xi^{-0.22} e^{-7|t|}$ $\[\xi \phi_{\text{IR}}(\xi, t) \propto \xi^{0.6+1.8|t|}e^{-2|t|} = \xi^{0.6}e^{(-2+1.8\ln\xi)|t|}$ **ZEUS fit parameters**

Reggeon and Pomeron component in cross section at EIC

4D cross section pseudodata

- Changing *t* slope as transitioning from Pomeron to Reggeon dominated region
- σ_r^D slowly varying with Q^2

$I\!\!R / I\!\!P$ ratio vs $-t$ for $\xi = 0.01, 0.1$ $\frac{1}{2}$ or $\frac{1}{2}$

- Change of ratio for small vs large ξ as a function of $-t$: different slope Γ
- \bullet *R*/*IP* < 1 for small $\xi \sim 0.02$
- $I\!\!R/I\!\!P > 1$ for larger $\xi \geq 0.1$: not accessible at HERA

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Parametrisation for fitting the pseudodata: full 4D fit IP+IR

- Treat the Pomeron and Reggeon contributions as symmetrically as possible
- Light quark separation not possible with only inclusive NC fits
- For both *and* $*IR*$ *fit the gluon and the sum of quarks*
- Generic parametrization at $Q_0^2 = 1.8 \text{ GeV}^2$:

 $f_k^{(m)}(x, Q_0^2) = A_k^{(m)} x^{B_k^{(m)}} (1-x)$ $C_k^{(m)}(1+D_k^{(m)}x^{E_k^{(m)}})$

where $k = q$, q and $m = I\!$, $I\!$

- Following sensitivity studies a suitable choice is:
	- f_q^{IP} has A,B,C parameters *q*
	- f_g^{IP} has A,B,C parameters *g*
	- $f_q^{\{R\}}$ has A,B,C,D parameters *q*

 $e^{B(m)t}$

 $\sqrt{\zeta^{2\alpha^{(m)}(t)-1}}$

- f_g^{IR} has A,B,C parameters *g*
- In addition fit for the parameters of the fluxes for $I\!\!P$ and $I\!\!R$: $\alpha(0), \alpha', B$

$$
\alpha^{(m)}(t) = \alpha^{(m)}(0) + \alpha^{'(m)}t
$$

Recovering the Pomeron and Reggeon inputs

Fit results with free Reggeon parametrization (solid) made to the pseudodata based on the GRV pion structure function (dashed)

Reggeon reproduced reasonably well

Pomeron reproduced almost perfectly

Uncertainties of diffractive PDFs: Pomeron

- relative uncertainty
- < few % or better in most regions
- larger uncertainty for gluon at large z (and also small z)
- normalization error at 2% is dominant at most regions (dashed red)

Pomeron quark data cut: $t \ge -1.5$ GeV²

linear horizontal scale note different vertical scale for gluons and quarks

Uncertainties of diffractive PDFs: Reggeon

- \bullet <2 % or better in most regions for quark except at large z
- Larger uncertainty for Reggeon gluon which is much smaller than Pomeron gluon
- Mild sensitivity to the cut on ξ for gluon, quark less sensitive
- Minimal sensitivity to the cut on *t*, dense vs sparse binning, lower luminosity $\mathcal{L} = 10 \text{ fb}^{-1}$

EIC can constrain Reggeon at similar level of precision as the Pomeron even when restricting data to $|t| \le 0.5$ **GeV² and** $\xi_{\text{max}} \approx 0.15 \div 0.2$

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Low energy scenario: 5 GeV x 41 GeV

- Low energy scenario: $E_e = 5 \text{ GeV} \times E_p = 41 \text{ GeV}$
- Kinematics restricted:
	- $\xi \geq 0.01$, by cms energy
	- $t \ge -0.6$ GeV², forward detector acceptance
- Reggeon dominated
- Fix Pomeron from HERA and fit only Reggeon
- Luminosity $\mathcal{L} = 10$ fb⁻¹

Low energy: Reggeon DPDFs and uncertainties

- Quark Reggeon constrained very well
- Larger uncertainty for Reggeon gluon which is much smaller than Pomeron gluon
- Two bands indicate sensitivity to two Monte Carlo samples: small variation

Low energy data at EIC can already determine Reggeon

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Summary

- **•Resummation at small x essential for stable results. Kinematical constraint. Combines DGLAP with BFKL.**
- Strong preasymptotic effects: modifies moderate x and small x region
- **•EIC will allow precision tests for saturation with nuclei. Longitudinal structure function more sensitive**
- **•Opportunities for inclusive diffraction at EIC: tagged protons**
- **•Good prospects for measurement the diffractive longitudinal structure function**
- **•4-D fit with Pomeron and Reggeon to the diffractive pseudodata**
- **•EIC can extract flux parameters and partonic structure of the subleading 'Reggeon' exchange with similar precision to the leading 'Pomeron' exchange**