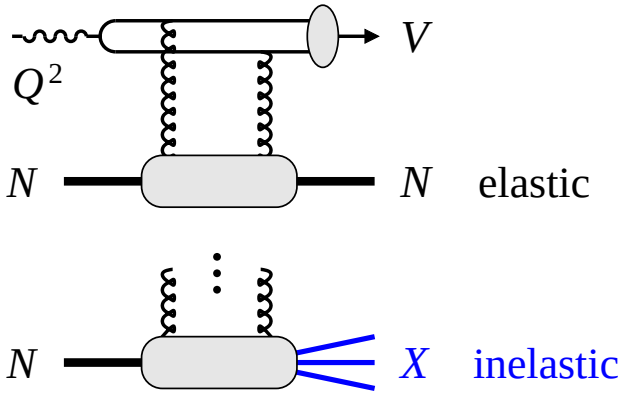
Probing quantum fluctuations of the nucleon's gluon density with inelastic diffraction at EIC

C. Weiss (JLab), EIC User Group Yellow Report Meeting, 20-Mar-2020 Jefferson Lab



Factorization theorem for hard exclusive vector meson production

$\times$

Theory of soft diffractive scattering with flucutating amplitude

- Concepts

  Hard exclusive vector meson production

  Diffractive scattering with fluctuations

- Gluon density fluctuations in nucleon

  Inelastic/elastic diffraction at $t = 0$
  Frankfurt, Strikman, Treleani, CW, PRL 101:202003, 2008

  Scaling model of fluctuations

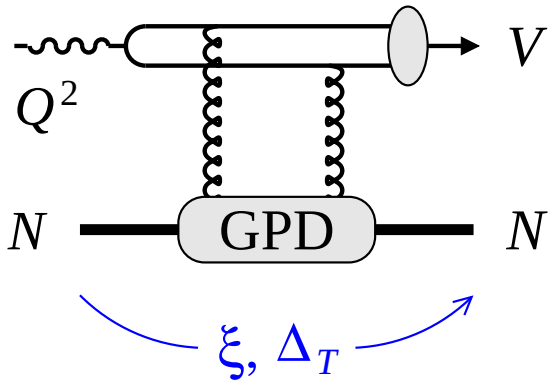
  HERA results ρ^0, ϕ

- EIC measurements

  Forward/far-forward detection requirements

  Commonalities w $N \to N^*$ transition GPDs, target fragmentation

Concepts: Hard exclusive vector meson production 2



- Hard exclusive vector meson production

  Hard scale Q^2, $M^2_{Q\bar{Q}} \gg \mu^2_{\rm had}$

  Collinear factorization L amp
  Collins, Frankfurt, Strikman 96

  Transverse size of $q\bar{q} \sim \lambda/Q$

  Probes gluon GPD of nucleon ($x \ll 0.1$)
  NLO calculations: Belitsky, Müller 01; Ivanov, Szymanowski et al. 04+

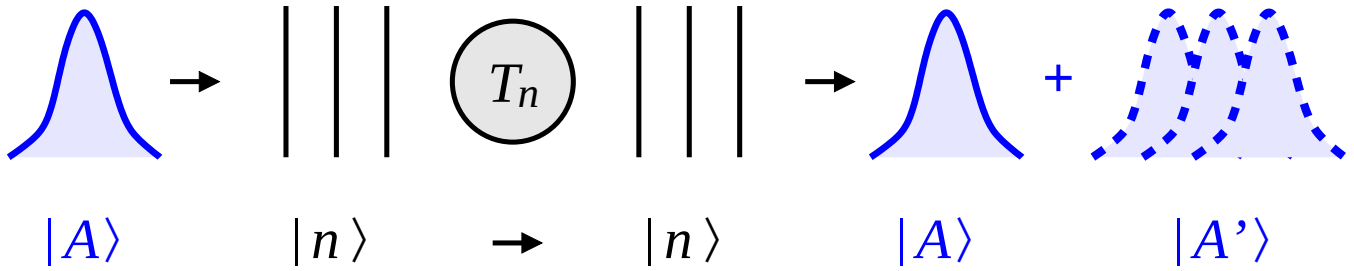
- Small-x gluon GPD can be constructed from gluon PDF + DGLAP evolution
  Frankfurt, Strikman, Koepf 97; Shuvaev, Golec-Biernat, Martin, Ryskin 99

- Extensively tested at HERA

  Kinematic dependences, absolute cross sections, soft-hard transition, universality

  New results: J/ψ photoproduction in UPCs at LHC

Concepts: Diffractive scattering



- Incoming wave packet $|A\rangle$

- Diffractive eigenstates diagonalize scattering amplitude T

  $|n\rangle \to T_n|n\rangle$, only absorption of wave $|n\rangle$, no transitions $m \neq n$

  $|A\rangle$ expanded in states $|n\rangle$

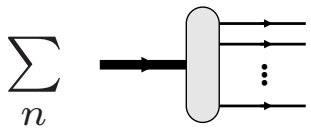
- Elastic and inelastic cross section

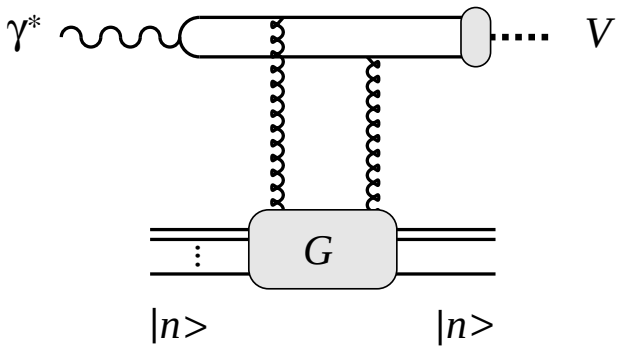
  $\sigma_{\text{el}}(A \to A) \quad \sim \quad \langle T\rangle^2$ quantum average in state $|A\rangle$

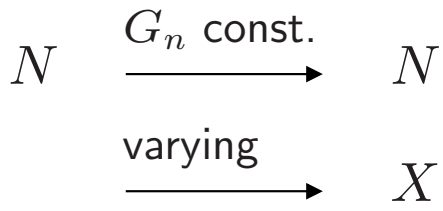
  $\sigma_{\text{inel}}(A \to A') \quad \sim \quad \langle T^2\rangle - \langle T\rangle^2$ quantum fluctuations

- Variations of scattering amplitude $T_n \neq T_m$ cause inelastic diffraction
  Good, Walker 60; Miettinen, Pumplin 78

Gluon density fluctuations: Hard diffraction







- Nucleon expanded in partonic states

  States with different particle number, spatial size, etc.

  Each state $|n\rangle$ has gluon density G_n

  Average gluon density $\langle G\rangle = \sum_n G_n$

  Can we observe quantum fluctuations?
  Frankfurt, Strikman, Treleani, CW, PRL 101:202003, 2008

- Hard diffractive processes at small x

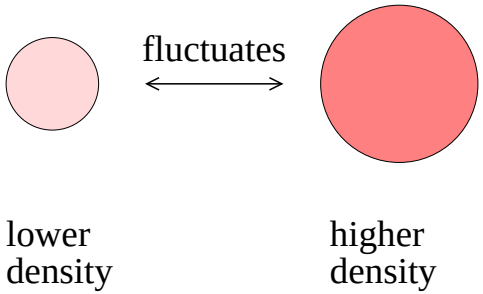
  Amplitude diagonal in partonic states $|n\rangle$,
  proportional to gluon density G_n

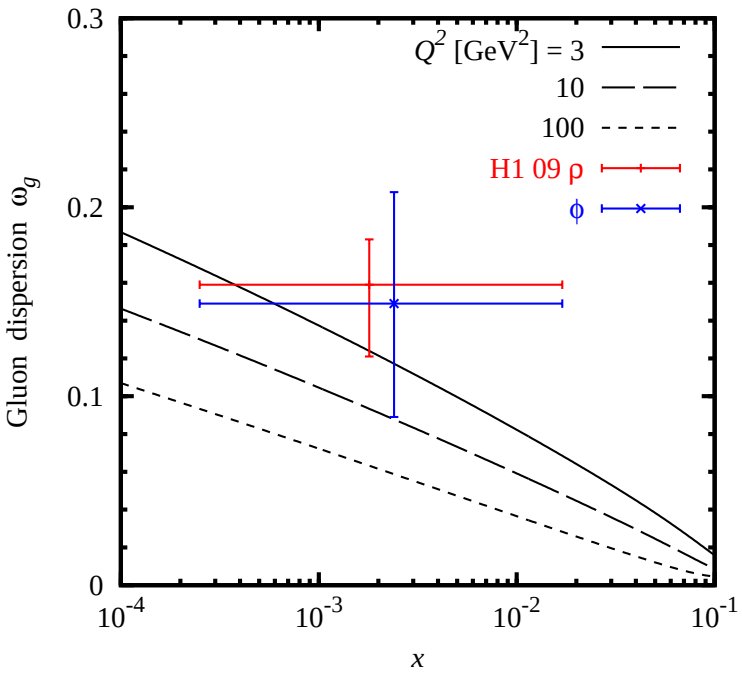
  Variations of G_n cause inelastic diffraction

$$\omega_g \equiv \frac{\langle G^2\rangle - \langle G\rangle^2}{\langle G\rangle^2} = \left.\frac{d\sigma/dt\ (\gamma^* N \to V X)}{d\sigma/dt\ (\gamma^* N \to V N)}\right|_{t=0}$$

[Related work in dipole model with saturation: Schlichting, Schenke 2014; Mäntisaari, Schenke 2016. Initial-state fluctuations in heavy-ion collisions Tribedy, Schenke, Venugopalan et al.]

Gluon density fluctuations: Dynamical origin





Frankfurt, Strikman, Treleani, CW, PRL 101:202003, 2008

- First estimate: Scaling model
  Close et al. 83: EMC effect

  Fluctuations of size change effective scale of non-pert gluon density $\mu^2(\text{gluon}) \propto R^{-2}$

  Size distribution from soft cross section fluctuations $\omega_\sigma \sim 0.25$ at $\sqrt{s} = 20\,\text{GeV}$

  Gluon density fluctuations change with x, Q^2 through DGLAP evolution

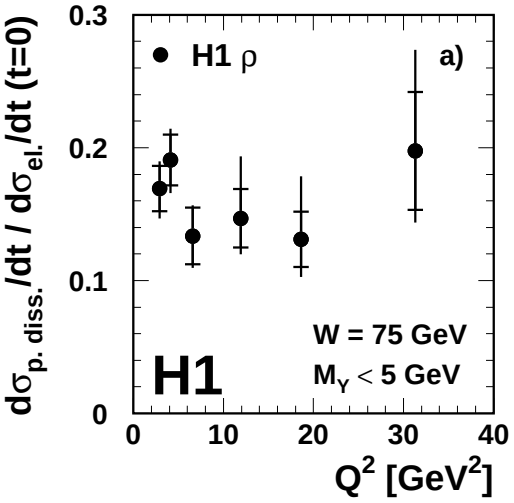
- Other scenarios

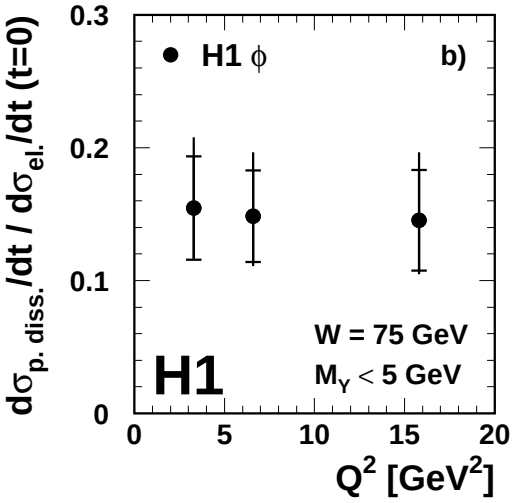
  Localized gluon fields active in chiral symmetry breaking, "hot spots"

- Fluctuations from DGLAP evolution

  Multiple radiation trajectories contribute to parton density at same x and Q^2

Gluon density fluctuations: HERA results





HERA H1 2009
exclusive vector mesons

- Diffractive vector meson production $e + p \to e' + V + p/X$

  $V = \rho^0, \phi$, $x = (10^{-4}, 10^{-2})$, $Q^2 = (0,$ few 10 GeV$^2)$

  Limited forward detection compromised inelastic/elastic separation at $|t| \gtrsim 1$ GeV^2

- Inelastic/elastic ratio roughly comparable with scaling model prediction

  Kinematic dependences not reproduced. Likely need fluctuations from DGLAP evolution

  Other scenarios?

Gluon fluctuations with EIC: Measurements

- Diffractive vector meson production $e + p \to e' + V + p/X$

  $V = J/\psi, \rho^0, \phi$, $x = (10^{-3}, 10^{-1})$, $Q^2 = (0,$ few 10 GeV$^2)$, $|t| = (0, \sim 1$ GeV$^2)$

  Need good t-coverage at low $|t| \sim 0.1$ GeV^2 for extrapolation to $t = 0$

- Forward-going system

  Elastic: proton, $x_L \approx 1 - x$, $p_T \lesssim 1$ GeV → far-forward

  Dissociative: X(mass $\lesssim 5$ GeV), contains $p, n, \pi; \Lambda, K$ → forward and far-forward

- Comments

  Test universality of gluon fluctuations by comparing different vector meson channels

  Same final states as $N \to N^*$ transition GPDs, baryon resonance production

  Good knowledge of dissociation important for measurements of elastic processes.
  Dissociative/elastic ratio rises at large $|t|$:

  $$\frac{d\sigma/dt\,[\text{dissoc}]}{d\sigma/dt\,[\text{elast}]} \sim e^{(B_{\text{elast}} - B_{\text{dissoc}})|t|}, \qquad B_{\text{elast}} - B_{\text{dissoc}} \approx 5 \text{ GeV}^{-2}$$ [HERA]

Gluon fluctuations with EIC: Physics interest

- Fluctuations are fundamental property of quantum systems.
  Place nucleon structure in QCD in context of other quantum systems

- Formulation based on collinear factorization, leading-twist operators.
  Extends concepts of PDF/GPD; universal property.

- Gluon fluctuations potentially connected with mechanism of
  chiral symmetry breaking in QCD ("mass generation")

- Interesting theoretical questions: Formal operator definition,
  fluctuations from DGLAP evolution, ...

- Connection with multiparton interactions MPI at LHC: New field of study
  Fluctuation effects in MPI: Frankfurt, Strikman, Treleani, CW, PRL 101:202003, 2008

Summary

- Quantum fluctuations of gluon density can be formulated in context of collinear factorization
- Dispersion of gluon fluctuations can be measured through inelastic/elastic ratio of VM production at $t = 0$
- Detailed studies of quantum fluctuations can/should be performed with EIC
- Results will challenge our understanding of nucleon structure and non-perturbative dynamics
- Fluctuations of parton densities affect other high-energy processes, e.g. rapidity gap survival probability in diffractive pp scattering
  Frankfurt, Strikman, Treleani, CW, PRL 101:202003, 2008; Frankfurt, Hyde, Strikman, Weiss, PRD 75:054009, 2007