Quantum fluctuations of parton densities in diffractive $ep$ scattering

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- Diffractive vector meson production

$$e + p \rightarrow \begin{cases} e' + V + p & \text{elastic} \\ e' + V + X & \text{inelastic} \end{cases}$$

Gluon fluctuations from inelastic diffraction

- Dynamical origin of fluctuations

  Scaling model

  QCD evolution

- Experimental studies

  HERA: Diffractive $\rho^0$ and $\phi$

  EIC: Quantitative studies of fluctuations
Quantum fluctuations: Inelastic diffraction

- Nucleon quantum many–body system: Partonic wave function has components with different particle number size, etc.

Usual DIS measures average parton density $\langle f \rangle = \sum_n f_n$

Can we observe quantum fluctuations?

- Hard diffractive processes at small $x$

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

Fluctuations of $G_n$ lead to dissociation
cf. soft diffraction: Good, Walker 60, Miettinen, Pumplin 78

$$\omega_g \equiv \frac{\langle G^2 \rangle - \langle G \rangle^2}{\langle G \rangle^2} = \frac{d\sigma/dt (\gamma^* N \rightarrow V X)}{d\sigma/dt (\gamma^* N \rightarrow V N)\bigg|_{t=0}}$$
Quantum fluctuations: Dynamical origin

- Fluctuations challenge our understanding of nucleon structure and non-perturbative dynamics

- First estimate: Scaling model
  Close, Roberts, Ross 83: EMC effect

  Fluctuations of nucleon size change normalization scale of non-perturbative gluon density
  \( \mu^2(\text{gluon density}) \propto R^{-2} \)

  DGLAP evolution: Dispersion of gluon density changes with \( x, Q^2 \)

- Fluctuations arise also from DGLAP evolution itself

  Parton at given \( x \) and \( Q^2 \) can arise from lower scale partons through emission or no emission
Quantum fluctuations: Experimental studies

- Experimental requirements
  Forward detection of elastic protons and low–mass diffractive states at $x < 0.01$
  Accurate $t$ measurements (coverage, resolution) for extrapolation $t \rightarrow 0$

- HERA: Diffractive $\rho^0$ and $\phi$
  Inelastic/elastic ratio comparable with scaling model prediction, but kinematic dependences not reproduced... likely needs fluctuations from DGLAP evolution

- EIC: Detailed studies of quantum fluctuations
  Dedicated forward detectors also for DVCS, meson production
  High luminosity permits fully differential measurements in $x$, $Q^2$, $t$
Summary and outlook

- Nucleon in QCD as quantum many–body system: Quantum fluctuations of parton densities
- Challenge understanding of non-perturbative QCD and nucleon structure
- Explore as next step after one-body densities (PDFs, GPDs)
- EIC will enable fully quantitative studies: Forward detection, luminosity
- Interesting theoretical questions: Formal operator definition, fluctuations from DGLAP evolution, . . .
- Fluctuations of parton densities affect other high-energy processes, e.g. rapidity gap survival probability in diffractive $pp$ scattering