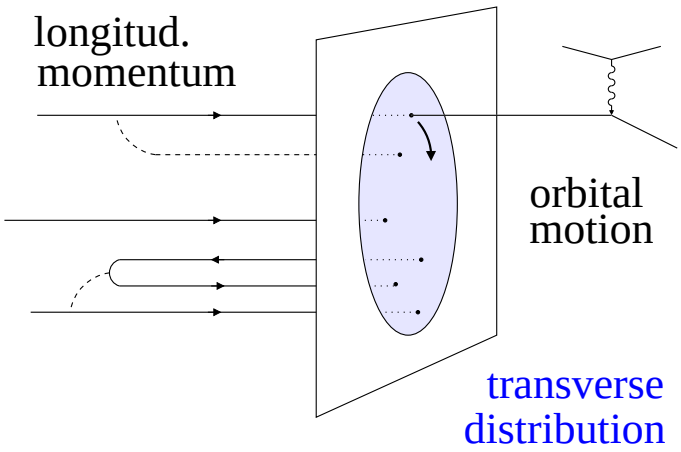
Gluon imaging and nucleon structure

C. Weiss (JLab), EIC Collaboration Meeting, Stony Brook, 10–Jan-10



- Gluon imaging with hard exclusive processes $\gamma^* N \to V + N \quad (J/\psi,\, \phi)$

  Physical interest

  Valence–like gluons at $x > 0.1$

  Gluon vs. quark size at small x

- Chiral dynamics in gluonic structure

  Large–distance gluons in "pion cloud"

  Gluonic structure of pion from knockout processes $\gamma^* N \to V + \pi + N$ **NEW**

- Quantum fluctuations of gluon density **NEW** from inelastic diffraction $\gamma^* N \to V + X$

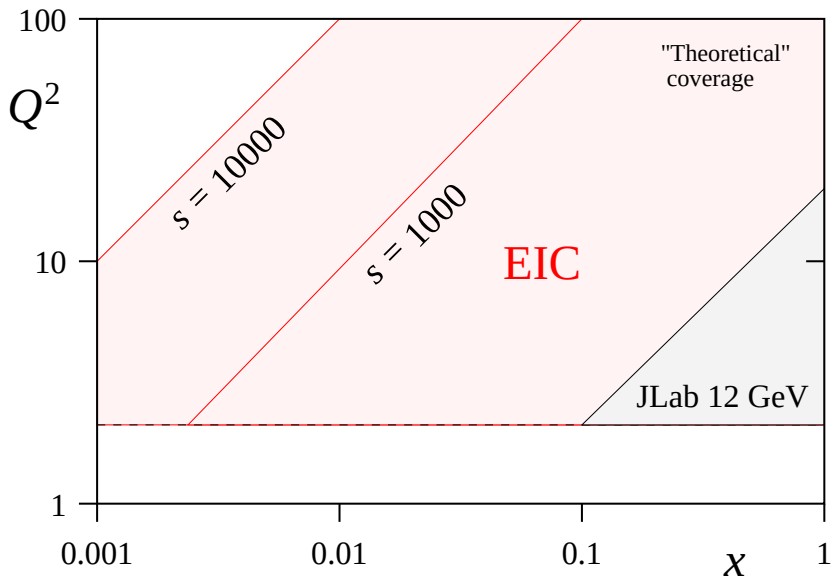
  Quantum fluctuations $\longleftrightarrow$ dissociation

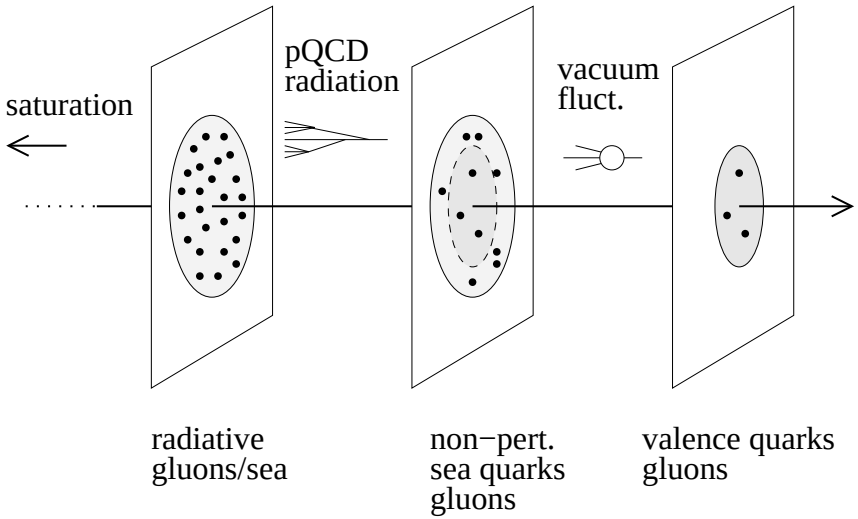
  Dynamical model

$\to$ Nucleon structure

$\to$ QCD dynamics in non-perturbative regime

Nucleon structure in QCD: Landscape





- Nucleon in parton picture is a quantum many–body system

  Different components of wave function

  Effective dynamics

- Components probed in ep scattering

  JLab 12 GeV — valence quarks

  EIC — sea quarks, gluons, Q^2 dependence

- Physical properties

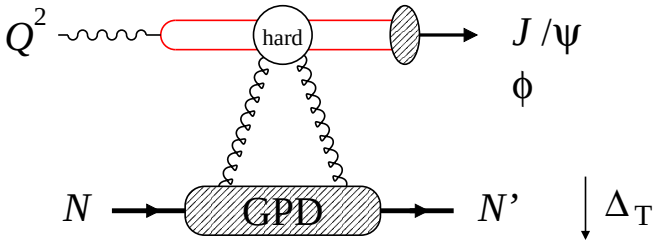
  Longitudinal momentum densities: PDFs

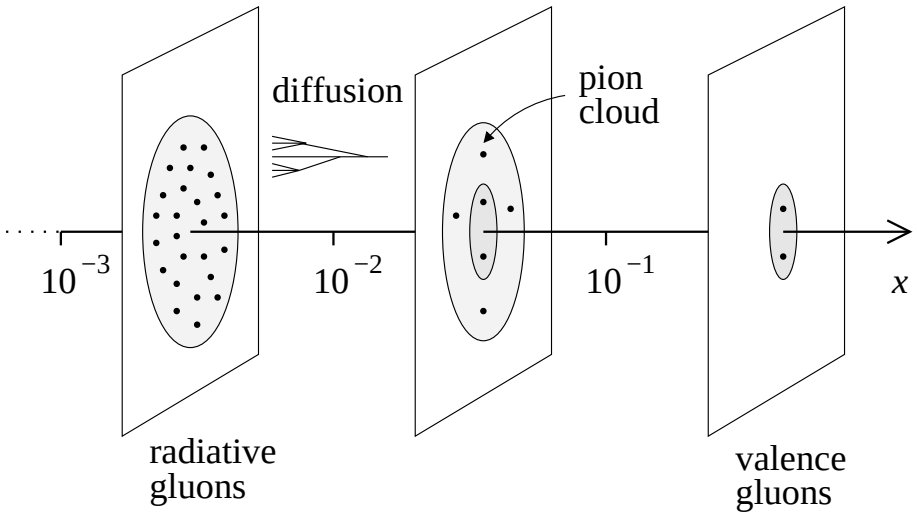
  Transverse spatial distributions: GPDs ←

  Orbital motion and correlations: TMDs, "higher twist"

  Quantum fluctuations ←

Gluon imaging: Probes, dynamics





HERA FNAL 82

- Gluon momentum densities known from inclusive DIS, jets

  Valence gluons at $x > 0.1$

- Transverse spatial distribution from exclusive J/ψ and ϕ ($Q^2 > 10\,\mathrm{GeV}^2$)

  Clean, simple! Transverse distribution directly from Δ_T dependence

  Reaction mechanism, QCD description studied at HERA

- Physical interest

  Valence gluons – dynamical origin?

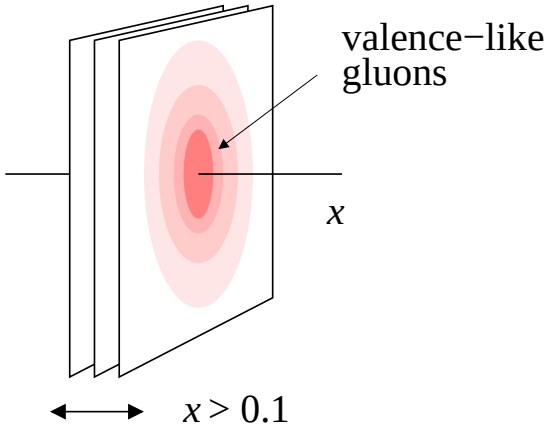
  Chiral dynamics at $b \sim 1/M_\pi$

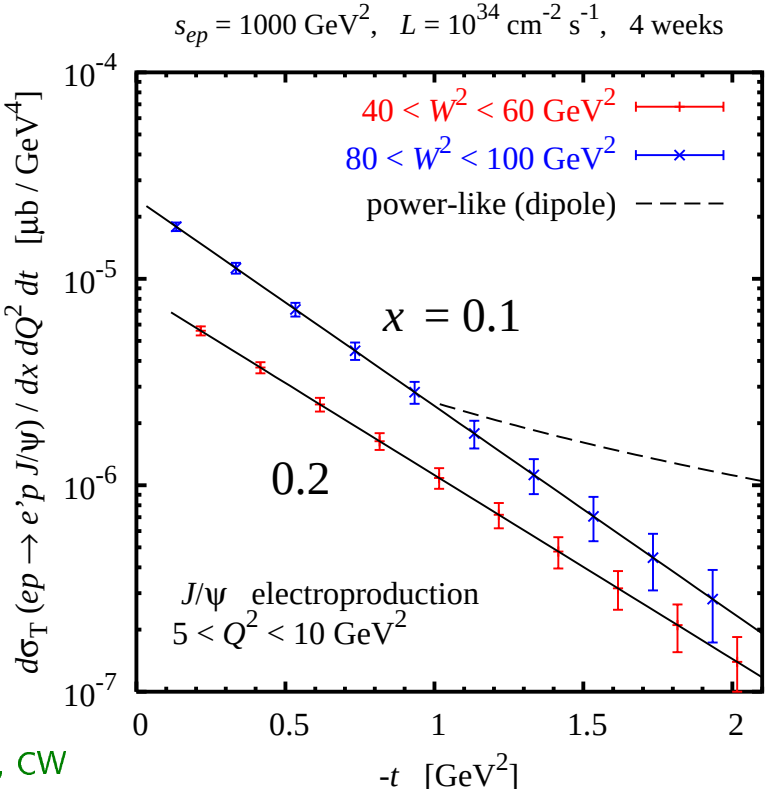
  Diffusion in QCD radiation

  Essential input for saturation: $Q_s \sim$ gluons/transverse area

  MC for pp@LHC, cosmic ray physics

Gluon imaging: Valence gluons





Hyde, CW

- EIC: Transverse imaging of valence gluons through exclusive $J/\psi, \phi$
- Needed for imaging

  Full t–distribution $\rightarrow$ Fourier
  Non-exponential? Power–like at $|t| > 1\,\mathrm{GeV}^2$?

  Electroproduction with $Q^2 > 10\,\mathrm{GeV}^2$:
  Test reaction mechanism, compare different channels, control systematics

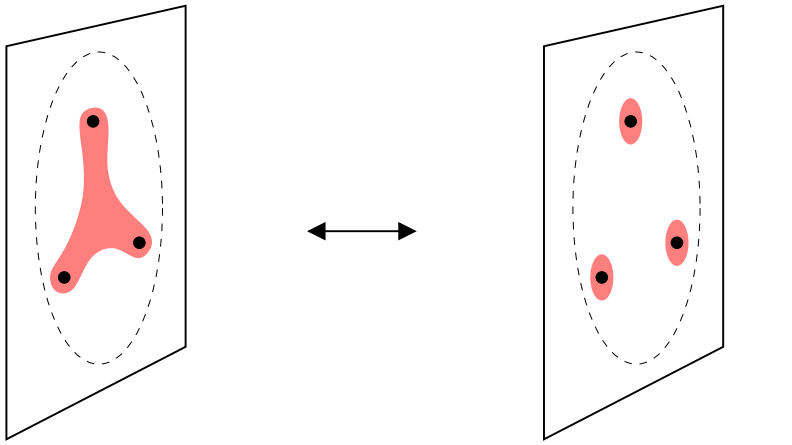
- Experimental requirements

  Recoil detection for exclusivity, t–measurements

  Luminosity $\sim 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for $x > 0.1$, electroproduction, high–t

First gluonic images of nucleon at large x!

Gluon imaging: Valence gluons



- Interpretation in dynamical models

  Flux tube: Gluon field "between" quarks, at center of nucleon

  Constituent quarks: Gluon field concentrated around quarks

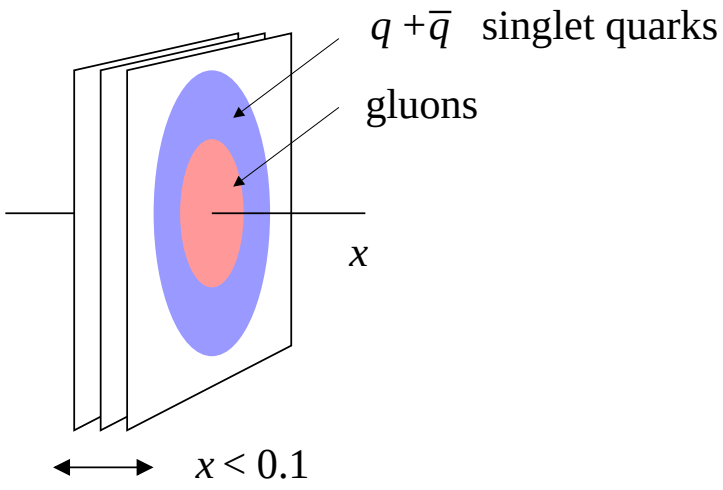
  Transverse distributions itself rigorously defined in QCD, only interpretation through models!

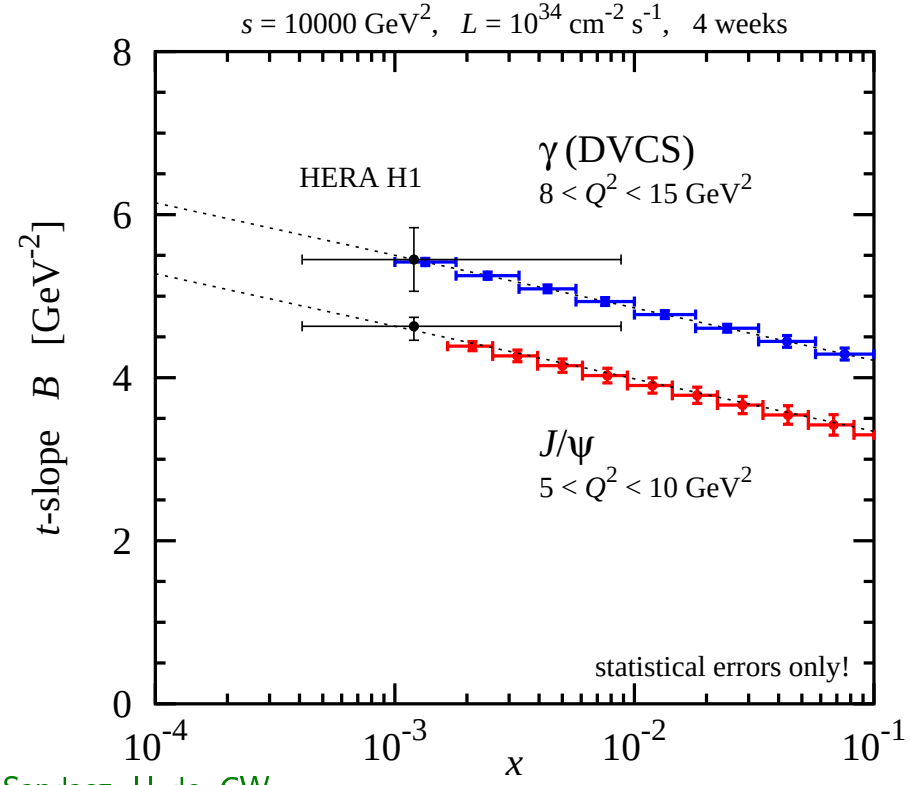
- Transverse distribution of valence gluons calculable in lattice QCD

  Large x: Moments $\rightarrow$ distribution

New QCD formulation of traditional nucleon structure ideas through GPDs

Gluon imaging: Gluon vs. quark size





Sandacz, Hyde, CW

- Do singlet quarks and gluons have the same transverse distribution?

  Hints from HERA:
  Area$(q + \bar{q})$ > Area(g)

  Difference expected from chiral dynamics:
  Pion cloud Strikman, CW 09

  No difference assumed in present pp MC generators for LHC!

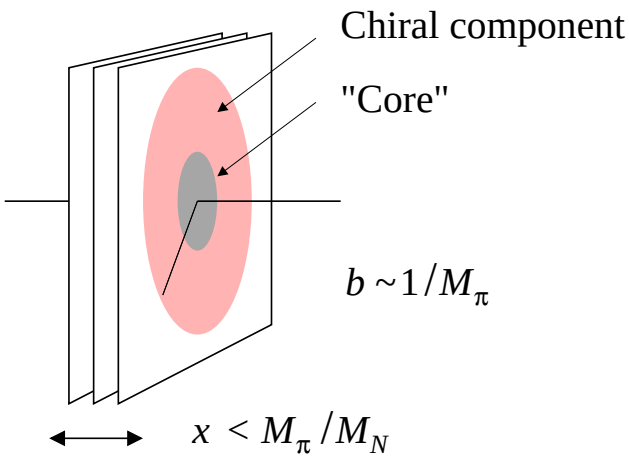
- EIC: Gluon size from J/ψ, singlet quark size from DVCS

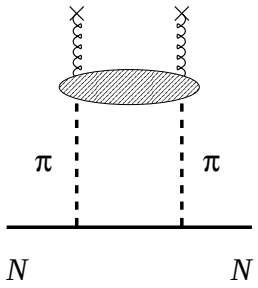
  x–dependence: Quark vs. gluon diffusion in wave function

  Detailed analysis: LO $\rightarrow$ NLO Müller et al.

Detailed differential images of nucleon's partonic structure

Gluon imaging: Chiral component



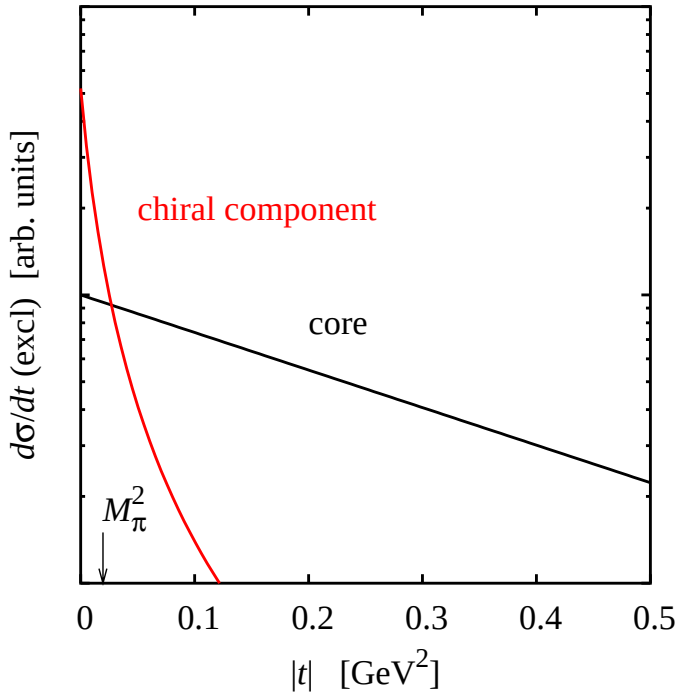


- Large–distance component of gluon density at $b \sim 1/M_\pi$ from chiral dynamics: "Pion cloud"

  Model–independent feature
  Strikman, CW 03/09

  Relation to transverse charge densities obtained from nucleon elastic FFs
  Miller 07

  Can we see it in exclusive $\gamma^* + N \to J/\psi + N$?

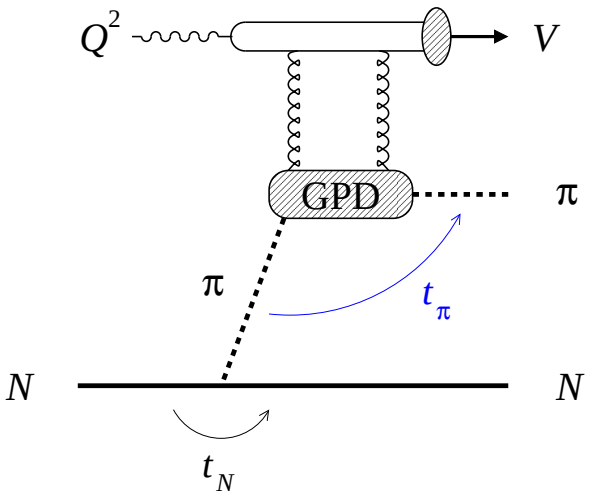


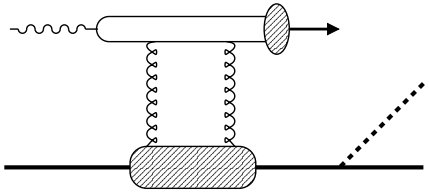
- Experimental requirements

  Accurate measurement of t–distribution for values $|t| \sim M_\pi^2 \sim 0.02\,\text{GeV}^2$

  . . . Should be studied for EIC!

Gluon imaging: Pion knockout processes





suppressed!

- Hard exclusive process on pion emitted by nucleon Strikman, CW 03

  $k_\pi^2 \sim M_\pi^2$ quasi-real

  Requires $x \ll M_\pi/M_N \sim 0.1$

- Kinematics with $p_T(\pi) \gg p_T(N)$ suppresses production on nucleon

  $F_{\pi NN}(t)$ softer than $\mathrm{GPD}_\pi(t)$

- Probe gluon GPD in pion at $|t_\pi| \sim 1\,\mathrm{GeV}^2$

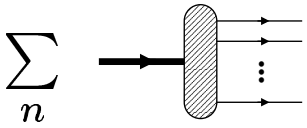
  Fundamental interest

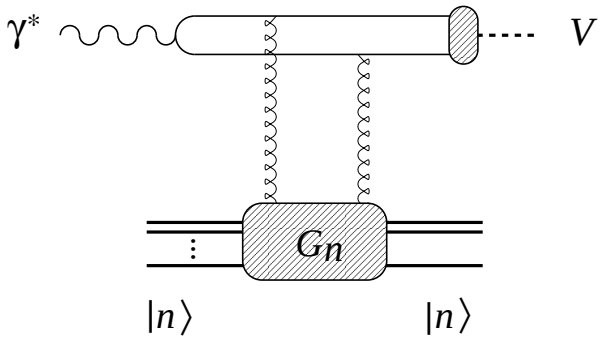
  Moments calculable in Lattice QCD

- Experimental requirements: Detection of forward nucleon and moderate–p_T pion

Direct probe of chiral component of partonic structure!

Quantum fluctuations: Diffractive dissociation





$$N \xrightarrow{G_n \text{ const.}} N$$

$$\xrightarrow{\text{fluctuating}} X$$

- 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?

  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

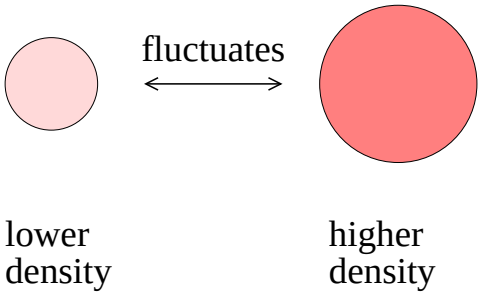
  Fluctuations of G_n lead to dissociation

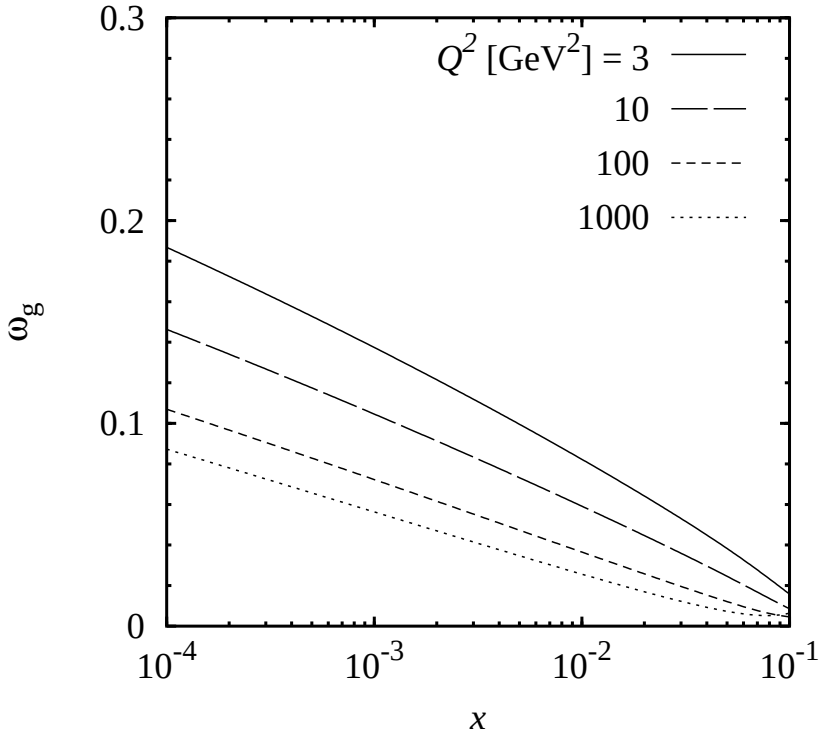
  cf. soft diffraction: Good, Walker 60, Miettinen, Pumplin 78

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

Fundamental characteristic of many–body system!

Quantum fluctuations: Dynamical model





- Example: Scaling model
  Close, Roberts, Ross 83: EMC effect

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

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

  Consistent with HERA data: Large uncertainties, unpublished

- Experimental requirements

  Detection of elastic and low–mass diffractive states at $x < 0.01$

  Accurate t measurements for extrapolation $t \to 0$

Summary

- Gluonic structure of nucleon largely unexplored
  . . . there is much out there to be learned!

- Transverse distribution of valence gluons (leading twist)
  calculable in lattice QCD, interpretable in dynamical models

- Chiral component of gluonic structure can be probed
  in small–t exclusive and knockout processes

  Interesting connection with low-energy chiral physics & its community

- Study of quantum fluctuations of parton densities
  next step after mapping of average densities (GPDs)