Small–size configurations: Origin and probes

C. Weiss (JLab), Mini–Workshop “Small–size configurations”, JLab, 25–Mar–11

- Elastic form factors: pion, nucleon
  Partonic representation
  Effective sizes
  Small–size vs. $x \rightarrow 1$ configurations

- Origin of small–size configurations
  Perturbative interactions
  QCD vacuum structure

- Probing small–size configurations with JLab 12 GeV
  Wide–angle Compton scattering
  Meson production at high $Q^2, t$
  Nuclear transparency
  $J/\psi$ production near threshold

High–$t$ photo/electroproduction
- Elastic FF, Compton
- Meson production, $J/\psi$
- Nuclear transparency
- Deuteron breakup

Conceptual framework
- Sizes ↔ dynamics
- More general than pQCD!
- Analogy with SRC in nuclei
Form factor: Parton picture

- Parton picture $P \to \infty$, $\Delta$ transverse
  
  Current cannot produce pairs

  Wave function overlap representation
  $F(t) = \sum_n \int dx \, d^2 k_T \, \psi_n^*(x, k_{T1}, \ldots) \psi_n(x, k_{T2}, \ldots)$

  Configurations with different particle number and transverse size

  Expect that large $t$ “select” small sizes
  How to quantify it?

- Transverse density

  $F(t) = \int d^2 b \, e^{i\Delta b} \rho(b)$

  Cumulative charge/current of constituents at transverse position $b$

  Reduction of GPD $\rho(b) = \int dx f_{q-q}(x, b)$

- Empirical charge density in pion

  Dispersion integral over timelike FF $e^+e^-$ data

  High density at $b \to 0$: Small–size configurations?
Form factor: Small–size configurations

- Two sources of small–$b$ density
  \[ x \sim \frac{1}{2} \quad \text{size} \ll R \quad \text{small–size} \]
  \[ x \to 1 \quad \text{size} \sim R \quad \text{end–point} \]

  Dynamical question!

- Density in center of pion mostly from small–size configurations

  End–point contribution constrained by quark density in pion at $x \to 1$
  Miller, Strikman, CW 10. $\pi A$ Drell–Yan data

- Alt. picture: Breit frame

  Photon reverses quark with $x \to 1$
  Feynman mechanism

Model–independent statement on small–size configurations!
Small–size configurations: Dynamical origin

- Perturbative interactions
  
  High–momentum component of wave function $k_T \sim R^{-1}$ wave function as source, $\int d^2 k_T$

  Responsible for leading $|t| \to \infty$ asymptotics of pion FF Efremov, Radyushkin 77+; Brodsky Lepage 80

- QCD vacuum structure
  
  Strong non–perturbative gluon fields of size $\rho \sim 0.2–0.3$ fm

  Objective measure: Average quark virtuality $\langle \bar{\psi} \nabla^2 \psi \rangle / \langle \bar{\psi} \psi \rangle > (0.7 \text{ GeV})^2$

  Lattice: Teper 87, Doi 02, Chiu 03

  Non–perturbative semi–hard component of WF

  Cf. short–range correlations in nuclei

  Chiral anomaly? $\gamma^* \gamma \to \pi^0$ puzzle

Evidence for non-perturbative small–size configurations!
**Small–size configurations: Nucleon**

- Nucleon more complex, more possibilities
  
  Uniform squeezing or diquark–like configurations?
  
  End-point configurations $x \to 1$?
  Related to large–$x$ parton densities \( JLab 12 \text{ GeV} \)
  
  Mean–field picture generally successful:
  Quark model, chiral soliton $N_c \to \infty$
  Nature of dynamical correlations?

- Correlated $q\bar{q}$ pairs
  
  Size $\rho \ll R$, induced by QCD vacuum structure
  
  Cf. Short–range correlations in nuclei
  
  Important in meson production processes!
  
  Strikman, CW, in progress
Small–size configurations: Other processes

- Get more information: $x$–dependence, quantum numbers, . . .

- Test universality!

- Details depend on channel
  
  Meson production: $\phi \leftrightarrow \rho^0$, $\rho^+$, $K^* \leftrightarrow \pi, K$, $\pi^+ \leftrightarrow \pi^0$, etc.

- Space–time picture needs to be developed
  
  Transverse frame $\leftrightarrow$ Center–of–mass frame

This presentation: Comments, suggestions, no definitive answers!
Processes: Wide–angle Compton scattering

- Compton process at $s, |t|, |u| \gg R^{-2}$

  Scattering from single quark: “Handbag” diagram

  Closely related to elastic FF at high $|t|$

  \[
  R(t) \sim \int \frac{dx}{x} \text{GPD}(x_1 = x_2 = x, t)
  \]

  $\rightarrow$ Talk Radyushkin

  Constituent quark model: Wave functions, quark helicity flip $\rightarrow$ Talk Miller

- Test reaction mechanism

  Polarization observables $A_{LL}, K_{LL}$

  $\rightarrow$ Talk Wojtsekhowski

  Finite virtuality $Q^2 \neq 0$ $\rightarrow$ Talk Hyde

$x$–distribution of small–size configs, nucleon helicity structure
Processes: Exclusive meson production

- $Q^2 \gg R^{-2}$: Meson produced in small-size configuration
  - Exp. test: $t$-slope becomes independent of $Q^2$
    - Seen in HERA VM data; some signs at CLAS 6 GeV
  - $Q^2 \rightarrow \infty$: QCD factorization theorem with pQCD interaction and GPDs
    - Collins, Frankfurt, Strikman 96
    - Small-size regime $\neq$ pQCD dominance

- Quantitative description based on non-perturbative interactions?
  - Knockout of small-size $q\bar{q}$ pair, may explain CLAS $\rho^0$, $\rho^+$ data
    - Cf. ERBL region of GPD
  - Also scattering from uncorrelated quarks
    - Cf. DGLAP region of GPD. Related by crossing, dispersion relations

- What about high-$t$ photoproduction?
  - Talks Ilieva, Strikman, discussion

Timelike Compton: Talk Stepanyan
Processes: Small–size configurations with 12 GeV

- **Nuclear transparency** \( \rightarrow \) Talks Cosyn, Horn, Gao, Gilman
  
  Small–size configurations experience reduced interaction with nuclear medium: Color transparency

  \( \phi, \rho \) photoproduction on nuclei

- **\( J/\psi \) photo/electroproduction** \( \rightarrow \) Talks Strikman, Fuchey, Chudakov
  
  “Naturally” small size even in photoproduction

  Clean probe of gluon field even at JLab energies

  Near–threshold \( |t_{\text{min}}| \sim 1 \text{ GeV} \leftrightarrow \) high–\( t \) form factors

  Reaction mechanism poorly understood near threshold: GPD for large longitudinal momentum transfer \( x_1 \neq x_2 \)? Re/Im ratio?

- **High-energy deuteron breakup** \( \rightarrow \) Talk Sargsian
  
  Small–size configurations in \( NN \) system

- **Hadronic 2 \( \rightarrow \) 2 processes at high \( t \)** \( \rightarrow \) Talk Strikman
Summary

- Small-size configurations key concept of hadron structure
  - More primary than specific interaction models
  - Contains, but is not limited to, pQCD interactions
  - Small-size configurations from non-perturbative interactions:
    Chiral symmetry-breaking forces in QCD vacuum

- Learn to discuss/describe high-momentum-transfer processes in terms of small-size configurations
  - Detailed modeling required: Space-time picture, effective interactions
    - Experiments should answer quantitative questions:
      Effective size distribution, shrinkage, . . .

- Many interesting options to probe small-size configurations with 12 GeV
  - Collider energies: Small-size configurations in photon’s $q\bar{q}$ wave function,
    diffractive scattering, nuclear shadowing EIC