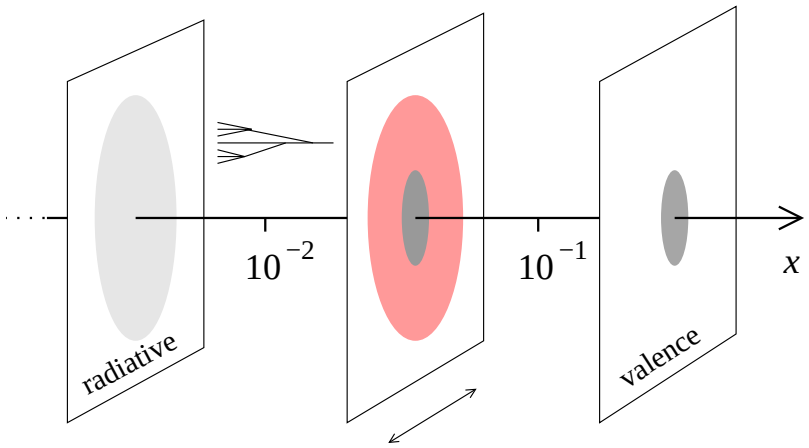
Chiral dynamics in high–energy processes

C. Weiss (JLab), INT Workshop "Gluons and the quark sea," Seattle, 16–Sep–10



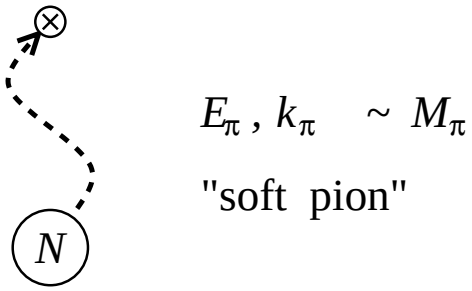
Large–distance dynamics
from QCD vacuum structure

↕

Parton picture of
hard processes (GPDs)

- Chiral component of partonic structure
  - Parametric region, universality
  - Parton densities $\bar{q}(x)$, $g(x)$
  - Transverse size $\langle b^2 \rangle$
- Probes in high–energy processes
  - Hard exclusive processes at $|t| \sim M_\pi^2$
  - Knockout processes $\gamma^* N \to N + \pi + V$
  - Chiral dynamics at small x
  - Transverse charge densities → Talk Miller
- QCD vacuum in partonic structure
  → Talk Kharzeev
  - Short–range correlations of partons
  - Multijet events in pp@LHC

Chiral component: Partonic representation



- Spotaneous breaking of chiral symmetry governs large–distance behavior of QCD

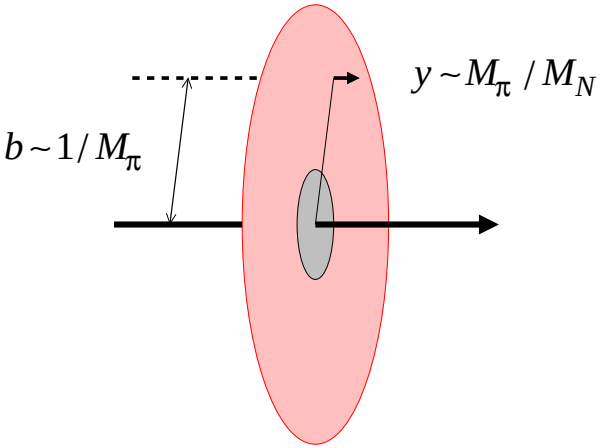
  π lightest excitation $M_\pi^2 \ll M_{\rm had}^2$

  Couples weakly to hadronic matter $\quad \propto k_\mu$

- Soft–pion contributions to nucleon properties

  Nucleon rest frame $\quad E_\pi, k_\pi \sim M_\pi$

  EFT: Pointlike sources, counter terms



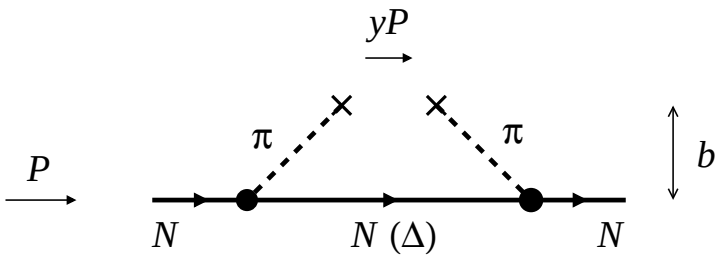
- Partonic representation $\quad P \to \infty$

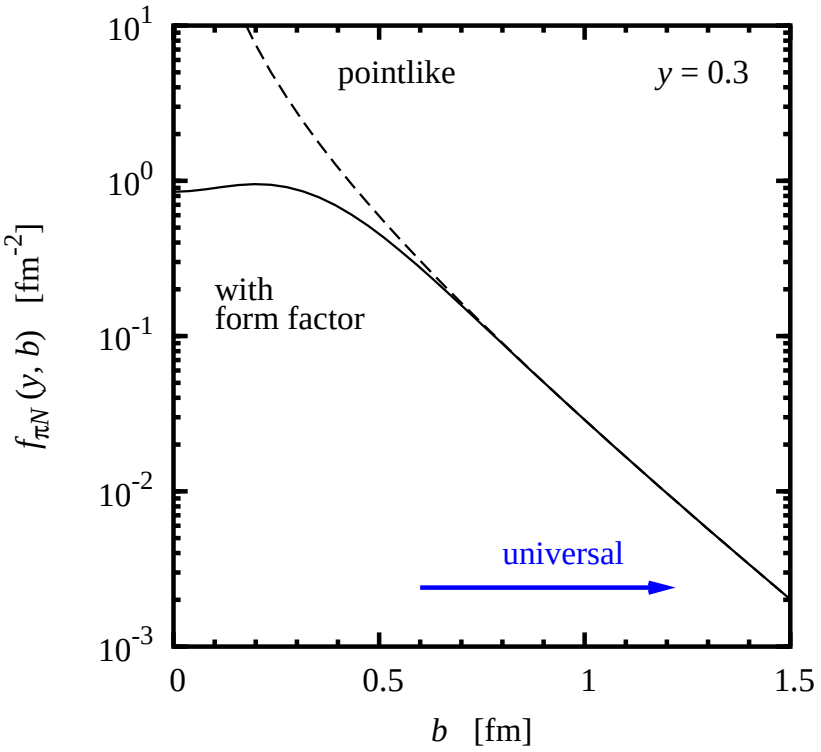
  $y \sim M_\pi/M_N$ $\quad$ longitud. momentum fraction

  $b \sim 1/M_\pi$ $\quad$ transverse distance

Soft pion slow, peripheral "parton"

Chiral component: Universality





- Impact parameter–dependent pion distribution in nucleon (GPD)
  Strikman, CW 03/09

  Independent of short–distance dynamics in πN form factors

  "Yukawa tail" at large b with y–dependent mass

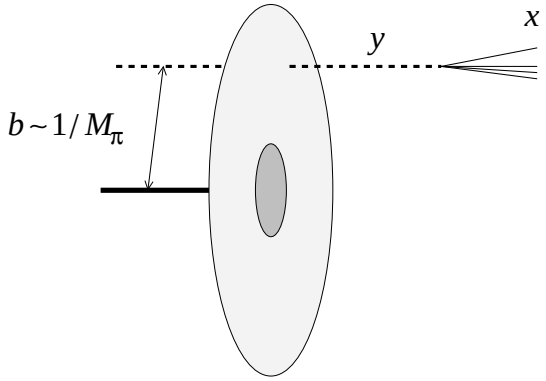
- Extension to $N \to \Delta$

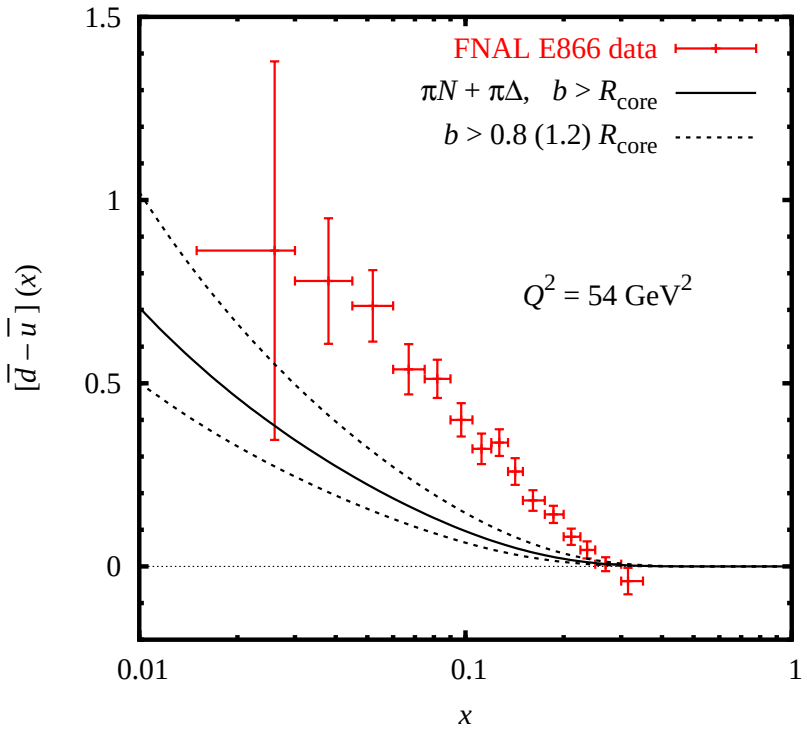
  Large coupling

  N, Δ degenerate in $N_c \to \infty$ limit

Universal pionic component at $b \sim 1/M_\pi$

Chiral component: Parton densities





- Chiral contribution to nucleon parton densities at $b \sim 1/M_\pi$

  Pion resolved locally on scale $1/M_\pi$

  $$\bar{q}(x,b) = \int_x \frac{dy}{y}\, f_{\pi N}(y,b)\ \bar{q}_\pi(x/y)$$

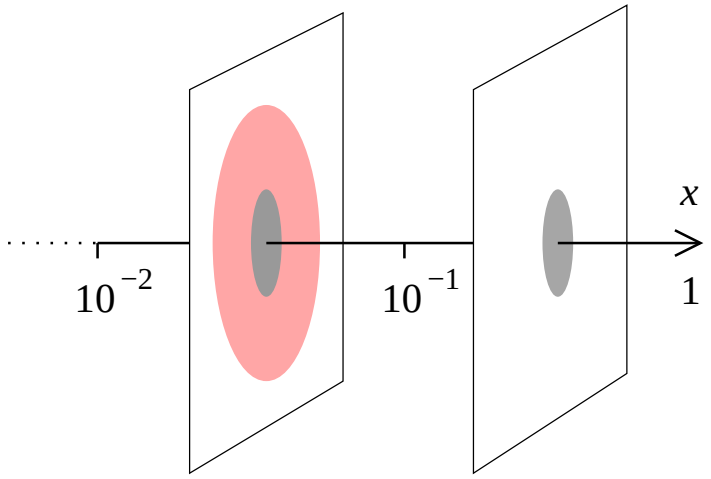
  Restrict to $b > R_{\rm core} \approx 0.6\,{\rm fm}$
  ↯ Pion cloud model Thomas 83, Jülich Group 90's

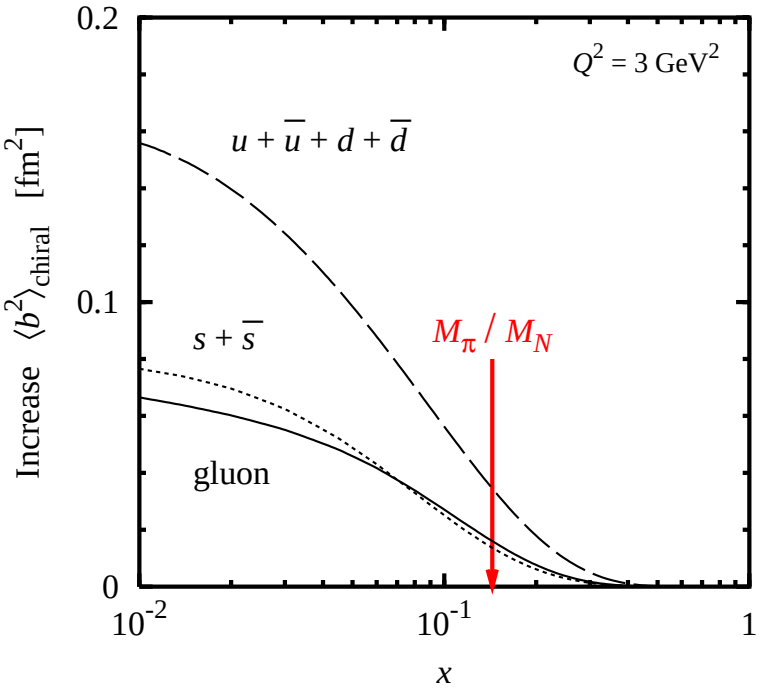
- How much of nucleon's parton content comes from chiral component? SW 09

  $$\bar{d} - \bar{u}: \quad \sim 1/3 \quad \text{from } b > R_{\rm core}$$
  $$\bar{u} + \bar{d}: \quad \sim 1/5$$

Most of non-perturbative sea
in non-chiral core at $b < 0.6\,{\rm fm}$

Chiral component: Nucleon transverse size





- Transverse partonic size of nucleon

$$\langle b^2 \rangle_f(x) \;=\; \frac{\int d^2b\; b^2\; f(x,b)}{\int d^2b\; f(x,b)}$$

cf. EM charge radius

Changes with x (and Q^2: DGLAP)

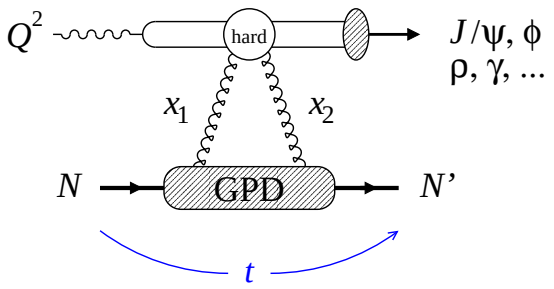
- Chiral component causes substantial increase below $x \sim M_\pi/M_N$

Calculable model–independently,
not sensitive to short-distance cutoff

Faster increase for quarks than
for gluons $\langle b^2 \rangle_{q+\bar{q}} > \langle b^2 \rangle_g$

"In addition" to change of non-chiral size

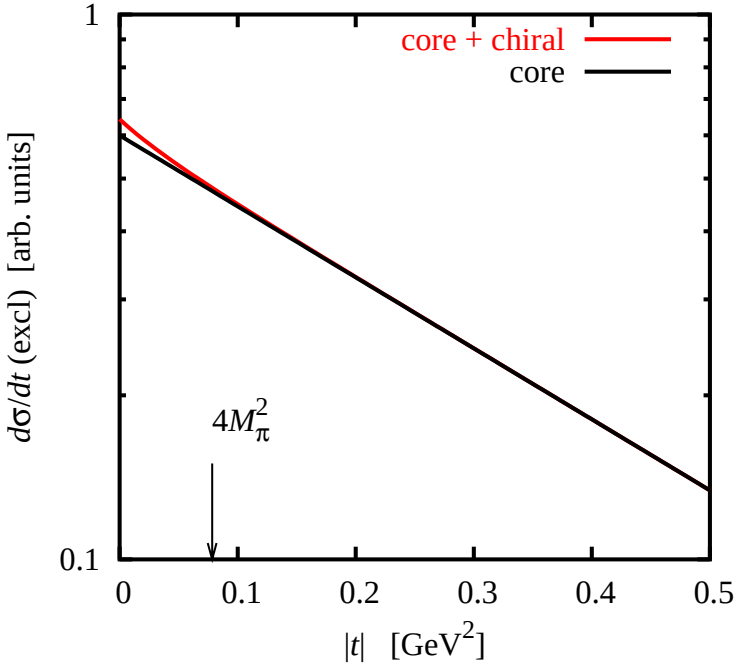
Probes: Hard exclusive processes



- Hard exclusive processes: Transverse quark/gluon imaging of nucleon

$$d\sigma/dt \quad \longrightarrow \quad H_f(x,t) \quad \overset{\text{Fourier}}{\longrightarrow} \quad f(x,b)$$

$$\langle b^2 \rangle_f \quad = \quad 4 \frac{\partial}{\partial t} \frac{H_f(x,t)}{H_f(x,0)} \bigg|_{t=0}$$

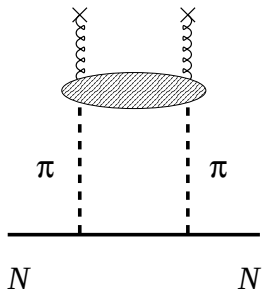


- Chiral component at $|t| \sim M_\pi^2$

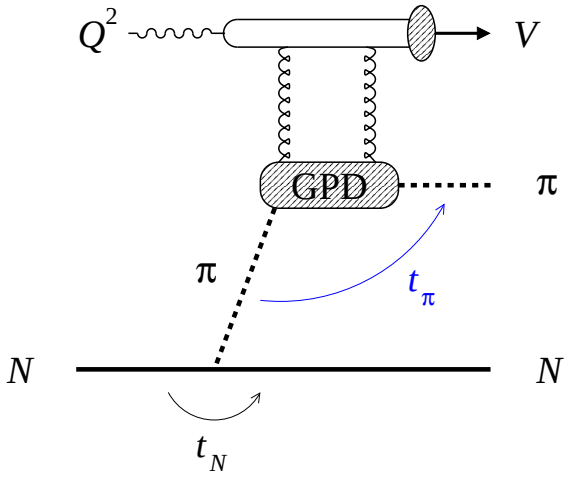
  Small effect. . . challenging!

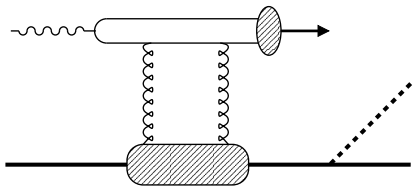
  Needs detailed modeling of non-chiral core

  Caution: $\langle b^2 \rangle$ difficult to determine by measurements at $|t| > 0.1$ GeV^2



Probes: Pion knockout processes





suppressed!

Strikman, CW 03;
see also Amrath, Diehl, Lansberg 08

- Hard exclusive process on pion emitted by nucleon

  $k_\pi^2 \sim M_\pi^2$ 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 $|t_\pi| \sim 1\,\mathrm{GeV}^2$

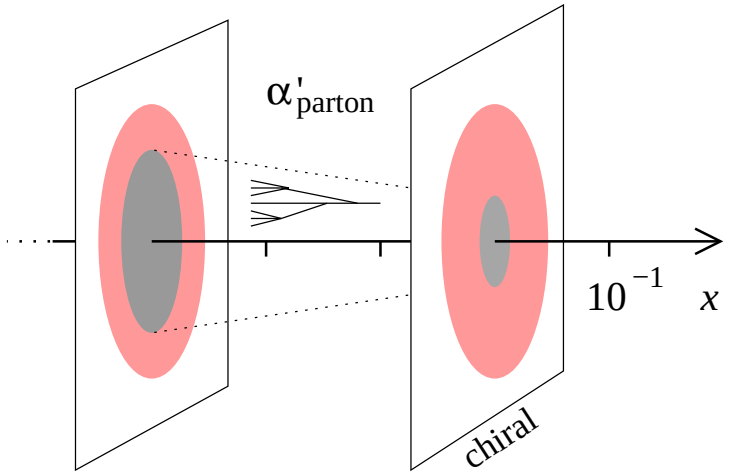
  Fundamental interest

  Moments calculable in Lattice QCD

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

Direct probe of chiral component!

Probes: Chiral component at small x



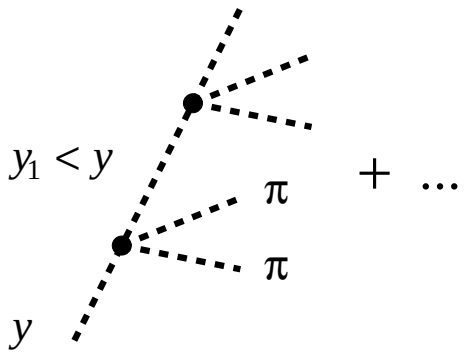
- Non–chiral core size grows due to Gribov diffusion

  Slow because
  $\alpha'_g(Q^2 \sim \text{few GeV}^2) \ll \alpha'_{\text{soft}}$

- Pion size can grow due to higher–order chiral effects

  Logarithmic terms resummed using functional methods Polyakov, Kivel 09

  Could become important at $x \ll 10^{-2}$

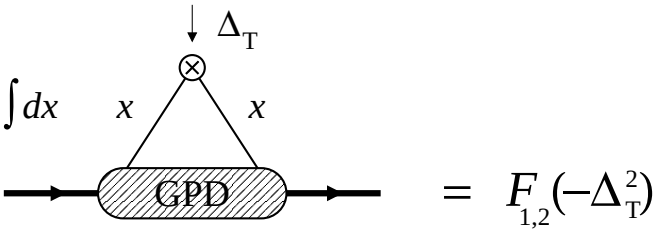


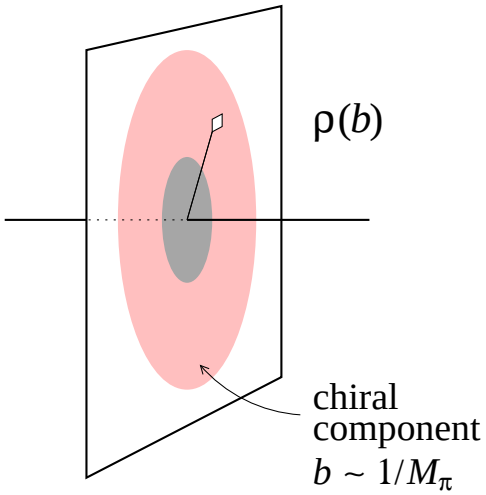
- Chiral component at large longituinal distances

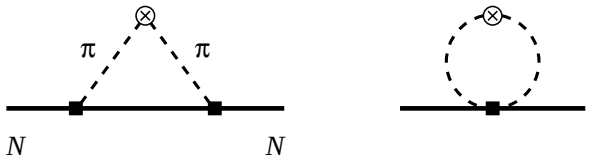
  Strikman, CW 09; in progress

"Single–step" chiral component should be safe for $x > 10^{-3}$

Probes: Transverse charge densities







- Transverse charge/current densities
  Soper 76, Burkardt 02, Miller 07

  Constrain valence quark GPDs $q - \bar{q}$

- Chiral dynamics at $b \sim 1/M_\pi$ Strikman, CW 10

  Equivalence between invariant ChPT and partonic picture of "pion cloud"

  Non-chiral core of charge density dominant up to distances $b \sim 1.5\,\mathrm{fm}$

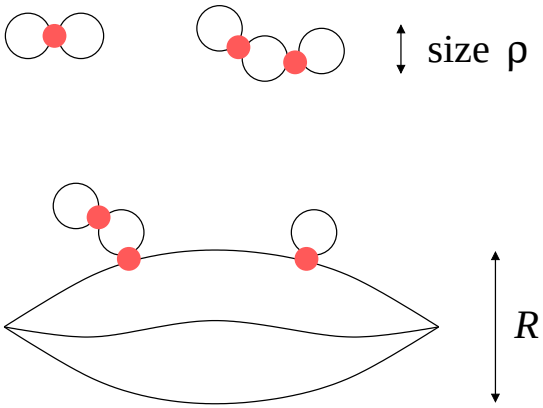
  Chiral component enhanced in magnetization density Miller, Strikman, CW; in progress

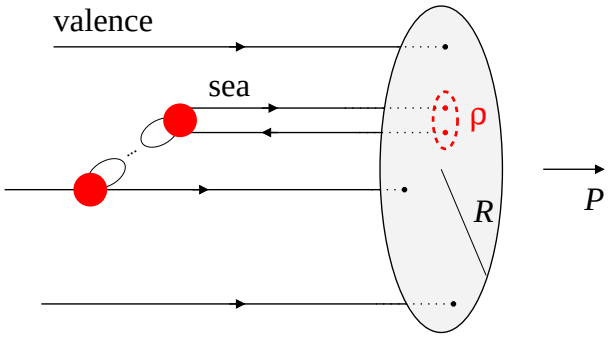
- Observable in low–t elastic scattering

  $t \to 0$ extrapolation of form factors vs. charge radii from atomic physics

Connection between deep–inelastic processes and low–energy elastic scattering

Correlations: QCD vacuum structure





- Chiral symmetry breaking: Non–perturbative gluon fields, condensate of $q\bar{q}$ pairs

  Localized with size $\rho \sim 0.3\,\mathrm{fm} \ll R$
  Shuryak 82; Diakonov, Petrov 84/86

  Objective measure is average quark virtuality
  $\langle\bar{\psi}\nabla^2\psi\rangle/\langle\bar{\psi}\psi\rangle > (0.7\,\mathrm{GeV})^2$
  Lattice: Teper 87, Doi 02, Chiu 03

  Coupled to valence quarks in Euclidean correlators

- Partonic picture: Short–range correlations in wave function

  Sea quarks in correlated pairs of size $\rho \ll R$

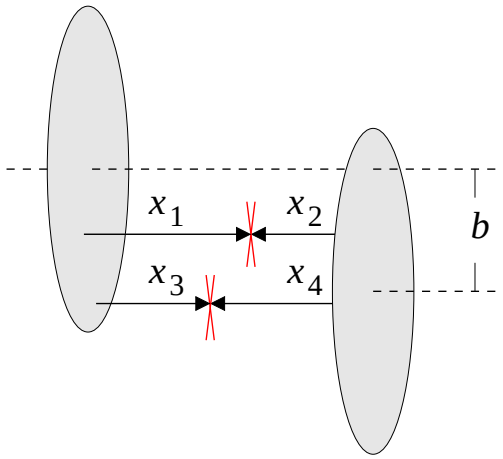
  Transverse gluon fields correlated with quarks

- Implications for DIS

  Intrinsic k_T of sea quarks in SIDIS
  Schweitzer, Strikman, CW 10

  Higher–twist corrections $\sim \rho^{-2}$ Balla, Polyakov, CW 97

Correlations: Multijet events in pp



$$\frac{\sigma(12;34)}{\sigma(12)\sigma(34)} = \frac{1}{\sigma_{\rm eff}}$$

$$\times \frac{f(x_1,x_3)f(x_2,x_4)}{f(x_1)f(x_2)f(x_3)f(x_4)}$$

- Transverse correlations increase probability of multiple hard processes

  FNAL CDF $\sigma_{\rm eff}$ two times larger than mean field with $R^2(x \sim 0.1)$

  Consistent with transverse correlations of size $\rho \sim 0.2 - 0.3$ fm

  Frankfurt, Strikman CW 04

- High probability of multiple hard processes in pp@LHC

  Detailed studies of parton correlations

  Needed in MC generators for pedestal of new physics signals

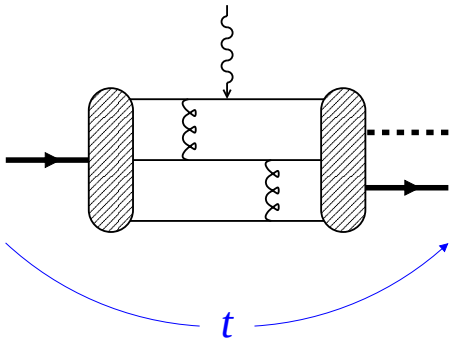
  Correlations reduce rapidity gap survival in central diffraction $pp \to p + H + p$

  Frankfurt, Strikman, Hyde, CW 06+

Chiral dynamics: Other aspects

- ChPT corrections to GPD moments, chiral extrapolation of lattice data
  Arndt, Savage 02; Belitsky, Ji 02; Ando, Chen, Kao 06; Diehl, Manashov, Schäfer 06/07, Kivel, Polyakov 02/08

- Soft–pion theorems for hard processes with near–threshold pion prod'n
  Pobylitsa, Polyakov, Strikman 01; Braun, Ivanov, Lenz, Peters 07



$W' \sim M_N + M_\pi$

Also: Backward pion production
Frankfurt, Polyakov, Strikman 99;
Lansberg, Pire, Szymanowski 07

- Chiral models of nucleon structure
  → Talks by B. Pasquini, I. Cloet

Summary

- Chiral component at $b \sim 1/M_\pi$ and $x < M_\pi/M_N$
  model–independent feature of nucleon's partonic structure

  Can be probed with knockout processes $\gamma^* N \to N + \pi + V$
  EIC has right energy range and forward detection capabilities

  Interesting connection between peripheral high–energy processes
  and low–energy ep elastic scattering

- Larger issue: Role of QCD vacuum in nucleon's partonic structure

  Short–range correlations between partons

  Numerous implications for DIS: Intrinsic k_T, higher twist

  Can be probed in multijet events at LHC: New field of study, practical importance

Nucleon as many–body system of partons:
Unifying theme for EIC ep physics program