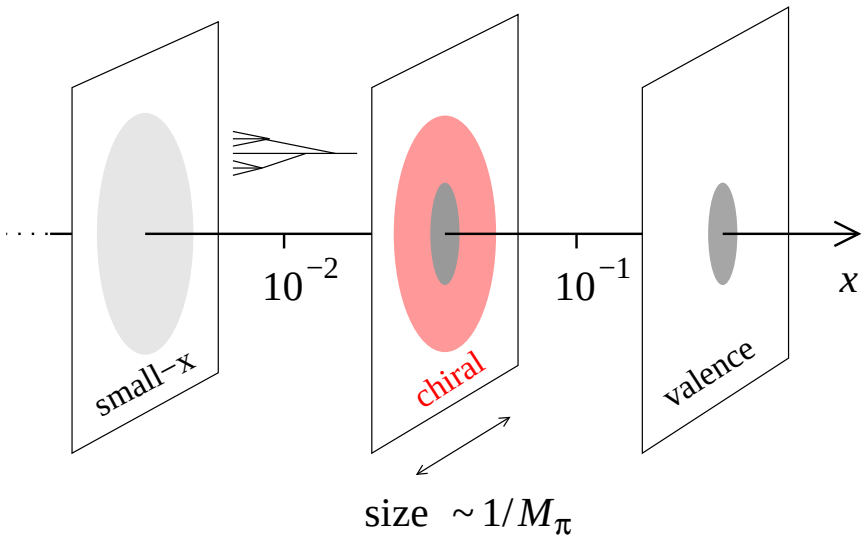
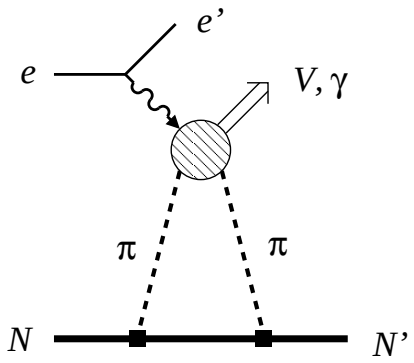
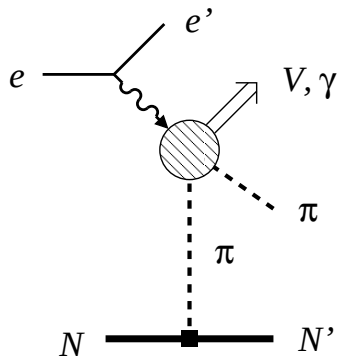
Probing chiral dynamics with an EIC

C. Weiss (JLab), POETIC V Workshop, Yale U, 22-26 Sep 14





exclusive

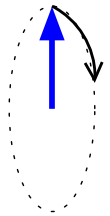


pion knockout

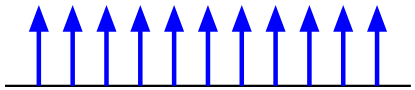
- Chiral dynamics
  - Spontaneuos symmetry breaking
  - Effective dynamics
- Peripheral partonic structure
  - Quarks/gluons at $b \sim 1/M_\pi$
  - Transverse size of nucleon
- Peripheral hard processes
  - Exclusive processes at low $|t|$
  - Pion knockout $\gamma^* N \to N + \pi + V$
- Connections and extensions
  - Chiral vs. small-x phenomena
  - Peripheral charge/current densities

Spontaneous symmetry breaking

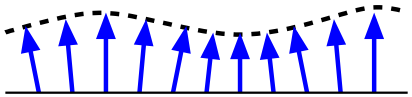
- Rotational symmetry in spin system



Rotational
invariance $O(3)$



$\boldsymbol{M} = \langle \sum \boldsymbol{S} \rangle \neq 0$
order parameter



spin wave
massless excitation

- Chiral symmetry in QCD

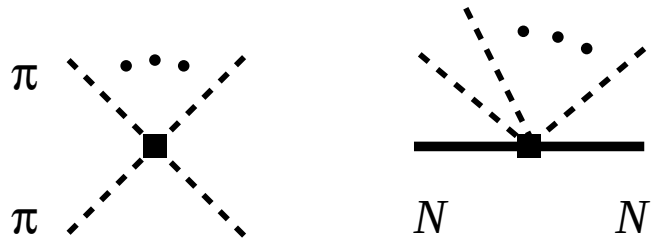
L, R independent
flavor rotations
$SU(2)_L \times SU(2)_R$

$\langle \bar{q}_L q_R \rangle \neq 0$
chiral condensate

$\langle ... \rangle \sim e^{i\boldsymbol{\tau}\boldsymbol{\pi}(x)}$
pion wave

- Determines large-distance, low-energy behavior

Chiral dynamics



- Effective dynamics

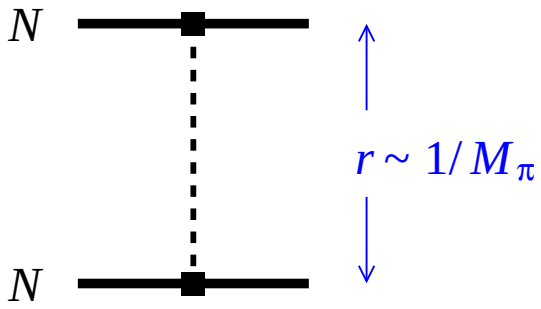
  Valid at momenta $p_\pi \sim M_\pi \ll M_{\rm had}$

  Structure determined by chiral invariance

  Pions couple weakly $\propto p_\pi^\mu$

  Nucleon as external source

  Formalized using EFT methods
  Gasser, Leutwyler 83; Weinberg 90. Extensive work



- Long-distance behavior of strong interactions

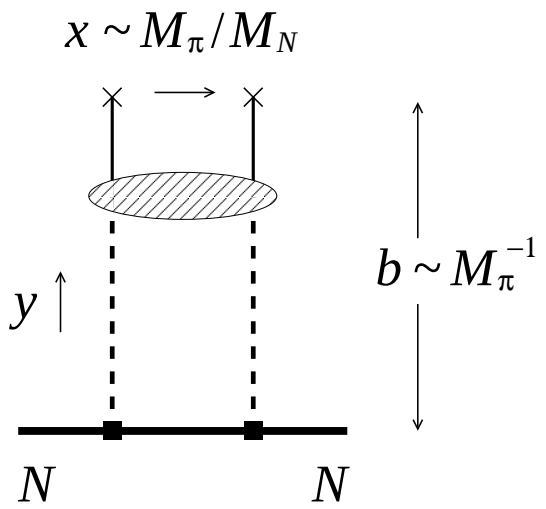
  Numerous phenomena

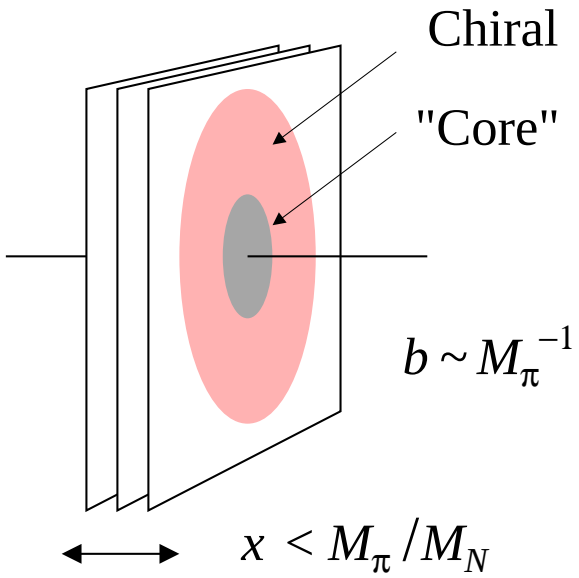
  $\pi\pi$ scattering

  NN interaction at distances $\sim 1/M_\pi$, Yukawa tail

  πN scattering, electromagnetic processes near threshold

Peripheral partonic structure





- Transverse spatial distribution (GPD)

  $f(x, b)$ longitudinal momentum, transverse position

- Chiral component

  $b \sim M_\pi^{-1}$ transverse distance

  $y \sim M_\pi / M_N$ momentum fraction of soft pion

  $x < y$ quark/gluon in pion

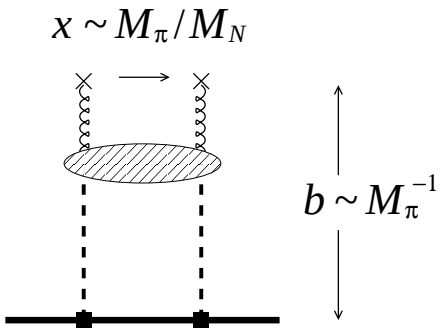
  Peripheral, slow partons

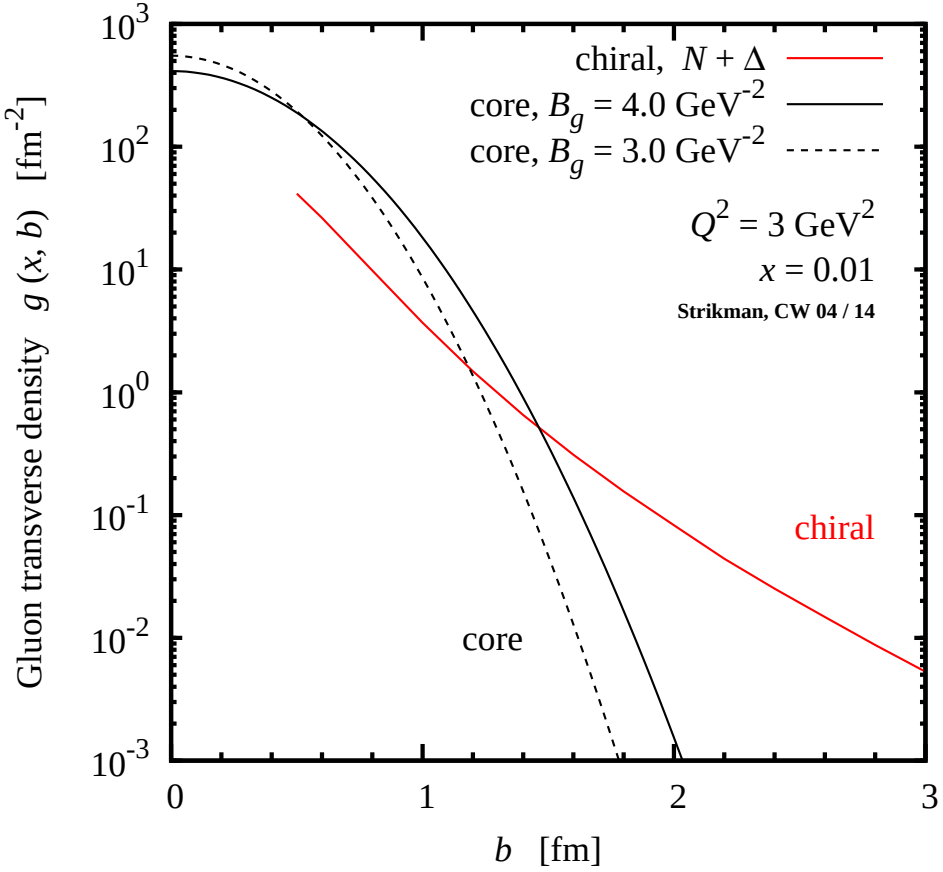
- Calculable model-independently
  Strikman, CW, PRD **69**, 054012 (2004); PRD **80**, 114029 (2009)

  Pion distribution in nucleon from chiral dynamics

  Parton distribution in pion from independent measurements

Peripheral gluon density





- Gluon transverse density

  Chiral component calculated
  Strikman, CW 04

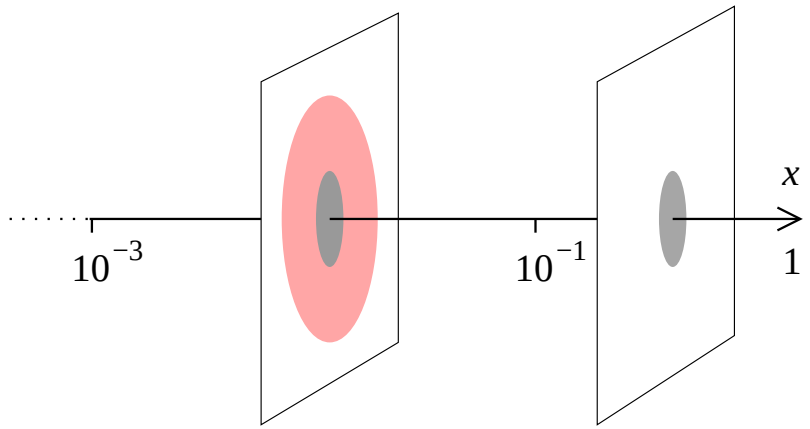
  Nonchiral core modeled empirically using J/ψ data
  HERA, FNAL

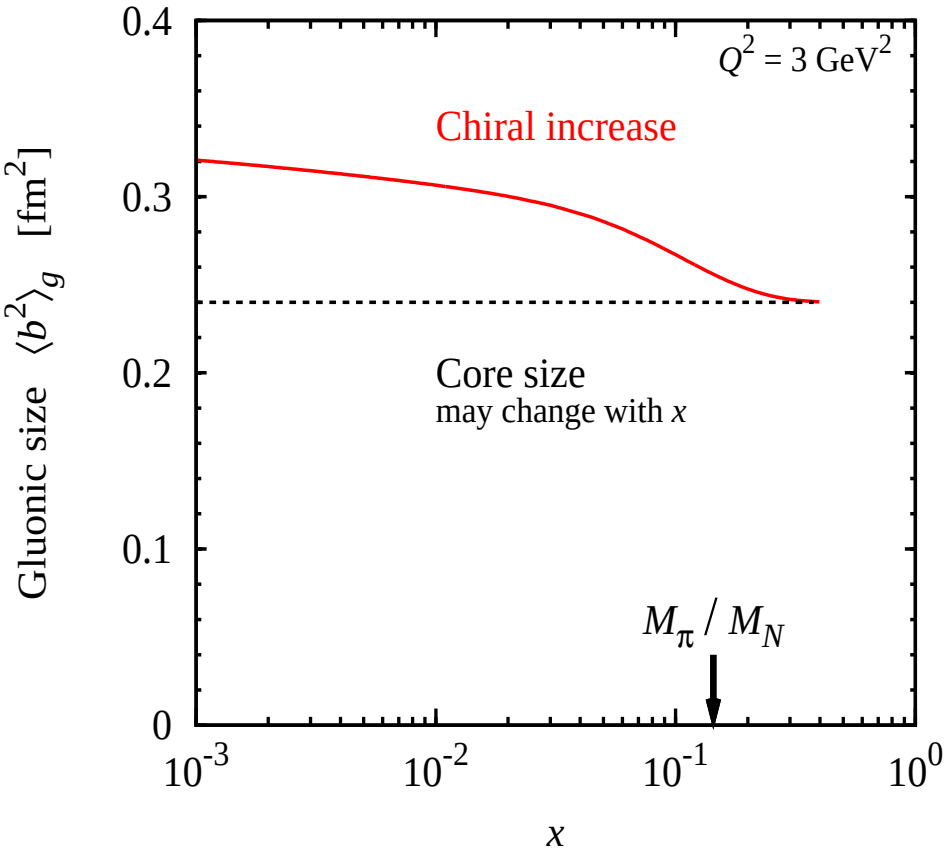
- Chiral component is distinct only at distances $b \gtrsim 2$ fm

- Small contribution to overall gluon density in nucleon
  percent level

Model-independent feature!

Nucleon transverse size





- Average transverse size

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

cf. EM charge radius

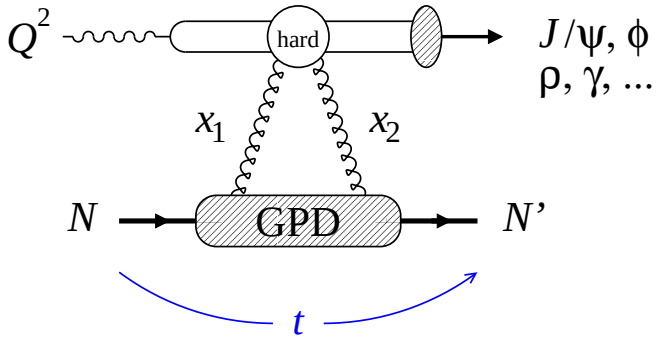
Changes with x and Q^2 (DGLAP)

- Chiral component causes increase below $x \sim M_\pi/M_N$
  Strikman, CW 04 / 09

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

- Size changes also due to non-chiral effects, $\langle b^2 \rangle$ cannot discriminate

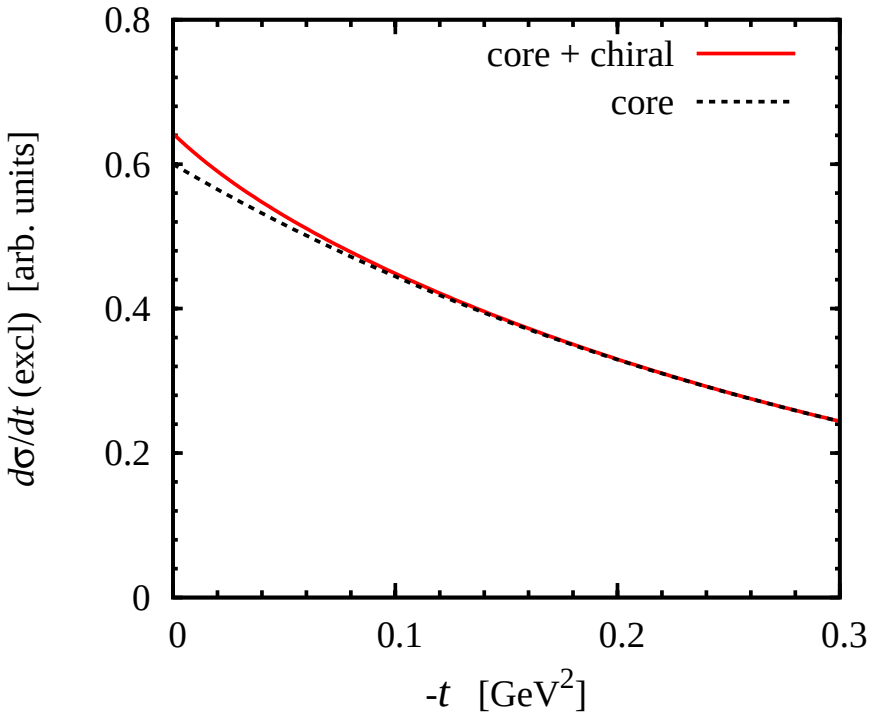
Hard exclusive processes



- Hard exclusive processes:
  Transverse imaging of nucleon

$$\frac{d\sigma}{dt} \;\to\; H_f(x_1, x_2, t) \;\overset{\text{Fourier}\ x1 = x2}{\longrightarrow}\; f(x, b)$$

$$\langle b^2 \rangle_f \;=\; 4 \frac{\partial}{\partial t} \left. \frac{H_f(x, x, t)}{H_f(x, 0)} \right|_{t=0}$$



- Effect of chiral component

  Numerically small

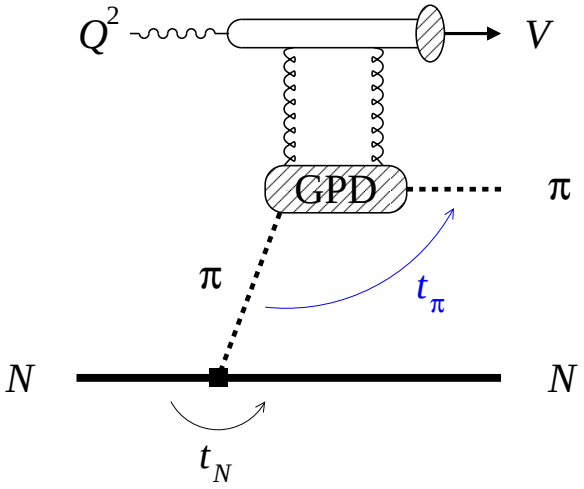
  Visible at $-t < 0.1\,\mathrm{GeV}^2$

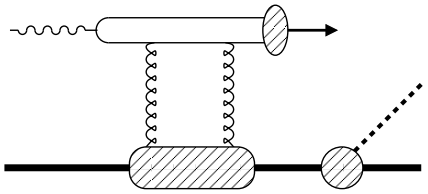
  Simple model estimate,
  needs detailed simulation!

- Caution when extracting $\langle b^2 \rangle$
  from measurements at finite $-t$

  Very challenging!

Peripheral pion knockout





suppressed!

- Hard exclusive process on soft pion
  Strikman, CW PRD69, 054012 (2004)

  $k_\pi^2 = O(M_\pi^2)$ pion soft

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

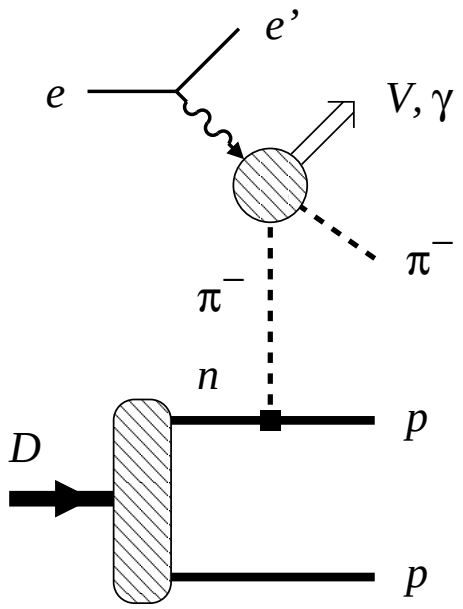
  Fundamental interest

  Moments calculable in LQCD

- Detection requirements
  Forward nucleon $p_T \sim 100\,\mathrm{MeV}$
  Forward pion $p_T \lesssim 1\,\mathrm{GeV}$

Direct probe of chiral component!
Needs detailed simulation...

Charged pion knockout with deuteron beam



- Charged pion knockout needs neutron in intial or final state

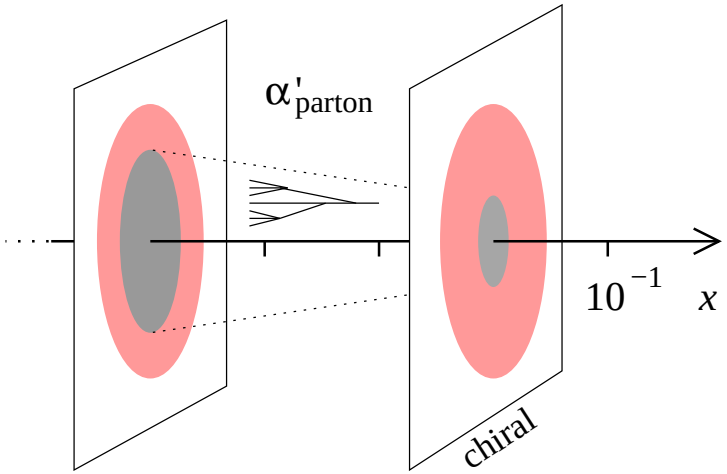
- Deuteron with proton tagging
  Keppel et al: Jlab 12 GeV proposal 2014

  Extrapolation to pion pole using measured momenta of pp system

  Low-energy final-state interactions in pp system from theory:
  New applications of chiral EFT!

- Excellent forward detection possible for charged particles
  MEIC JLab LDRD 2014 project

Chiral vs. small–x phenomena



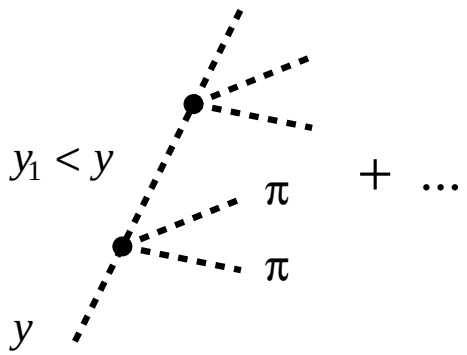
- Non–chiral core size grows due to Gribov diffusion

  Slow because $\alpha'_{\rm gluon}(Q^2) \ll \alpha'_{\rm soft}$

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

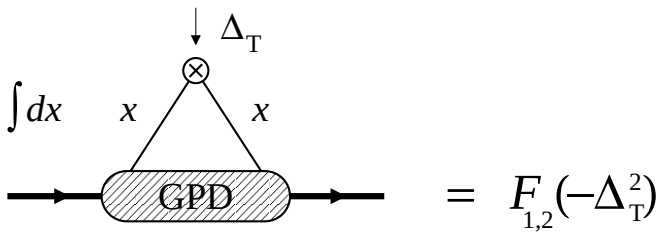
  Logarithmic terms resummed using functional methods
  Polyakov, Kivel 08; PK + Vladimirov 09; Perevalova et al 11

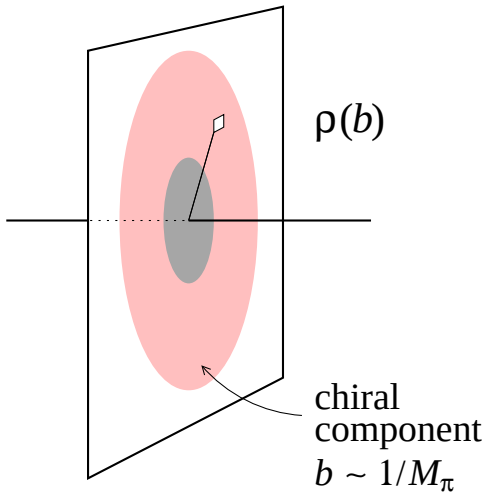
  Could become important at $x \ll 10^{-2}$

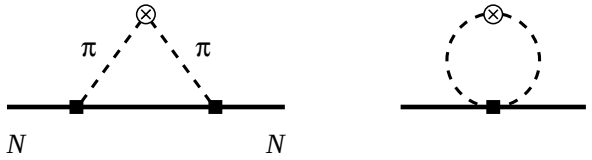


"Single–step" chiral component should be safe for $x > 10^{-3}$

Transverse charge and current 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 PRC **82**, 042201 (2010);
  Granados, CW JHEP **1401**, 092 (2014)

  Equivalence of Lorentz-invariant χPT and partonic formulation

  Chiral component dominant at distances $b \gtrsim 2\,\mathrm{fm}$

- Observable in low–t elastic scattering

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

Connect peripheral hard processes with low–energy elastic scattering

Summary

- Chiral dynamics generates distinct component of partonic structure at $x < M_\pi/M_N$ and $b \sim 1/M_\pi$

- Effect on t–slopes of hard exclusive V/γ production at $|t| < 0.1\,\mathrm{GeV}^2$ probably difficult to see

- Direct probes of chiral component in peripheral pion knockout look promising, merit detailed study

Related topic: Microscopic chiral-symmetry-breaking interactions in QCD
$\rightarrow$ Small-size $q\bar{q}$ pairs in partonic wave function
$\rightarrow$ Sea quark transverse momenta $p_T(\mathrm{sea}) \gg p_T(\mathrm{valence})$
$\rightarrow$ Parton short-range correlations
Could be probed with semi-inclusive and hadron correlation measurements at EIC