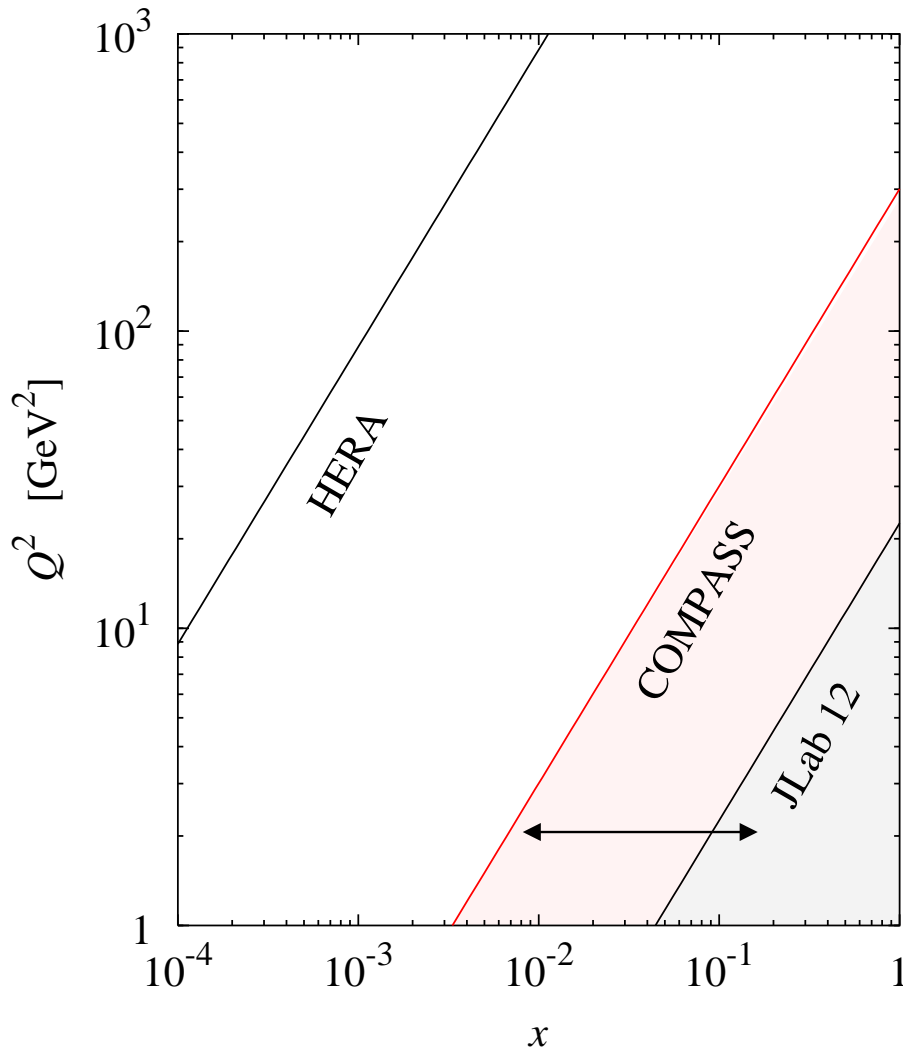# Exclusive processes and nucleon structure in the transition region

C. Weiss (JLab), GPDs@COMPASS Workshop, CERN, 04–Mar–2010

- Physics of transition region

  Nucleon structure landscape
  Exclusive processes at $0.01 < x < 0.1$

- Transverse distribution of partons

  Gluons from $J/\psi, \phi$

  Quarks vs. gluons from $\gamma \leftrightarrow J/\psi$

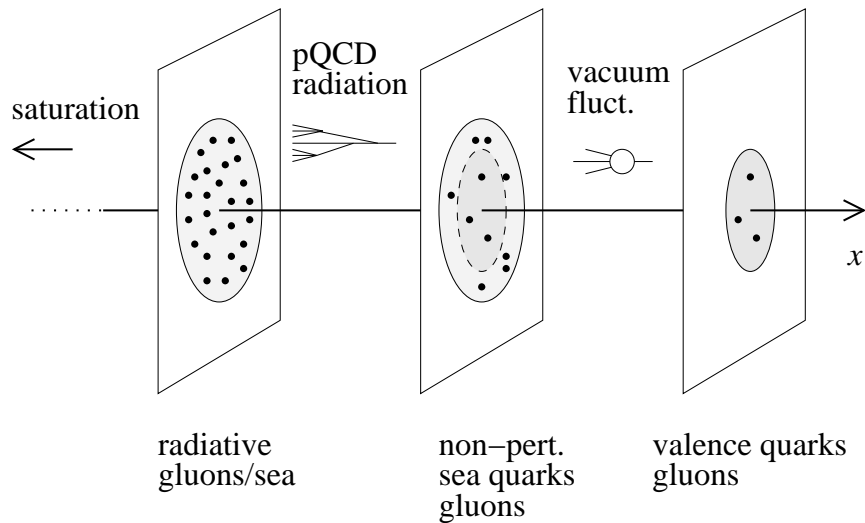 Chiral component from small t,
  pion knockout processes

- Non-singlet channels at $x < 0.1$

  Nucleon/meson structure from ρ^+, π, K

- GPDs from $ep/\mu p$ for pp@LHC

  Transverse nucleon structure in pp
  Saturation at small x

Nucleon structure: Landscape

saturation ←

pQCD radiation

vacuum fluct.

x

radiative gluons/sea

non–pert. sea quarks gluons

valence quarks gluons

- **Physical properties**

  Parton densities

  Transverse spatial distributions ←

  Orbital motion, angular momentum

  Correlations: transverse, longitudinal

- **Nucleon in parton picture: Many–body system!**

  Different components of wave function, effective dynamics

- **Dynamical regions**

  Valence region $x > 0.2$
  Valence quarks, gluons
  Effective few–body description $3q, 5q$
  Lattice $\rightarrow$ PDF/GPD Moments

  Transition region $\sim 0.01 < x < 0.2$
  Non–perturbative sea, gluons
  Vacuum structure, chiral dynamics

  Small–x region $x < 0.01$
  Gluons, singlet sea $q + \bar{q}$
  QCD radiation, diffusion, saturation
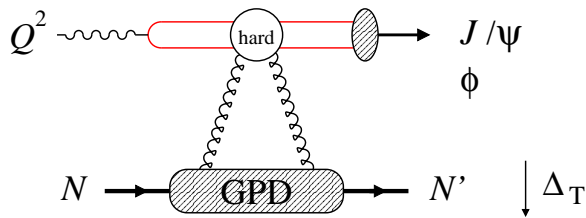
Exclusive processes: Transition region

	$x < 0.01$	$x > 0.2$
Cross sections	Gluon/singlet quarks $J/\psi, \phi, \rho^0, \gamma$ vs. non-singlet quarks ρ^+, π, K	valence quark dominance $\rho^+ \approx \rho^0, \phi \ll \rho^0$
Skewness	Theoretically controlled: QCD evolution, t–channel GPD parametrizations $R = $ DVCS/DIS $t \approx -\Delta_\perp^2$ transverse imaging	Essentially non-perturbative: Longitudinal correlations $t_{\min}$ large, $t = f(\xi, \Delta_\perp)$
Higher twist	Space–time picture: Dipole model HT $\sim$ finite size of $q\bar{q}$ Successful phenomenology	Challenging! Sudakov suppression

$$\longrightarrow \quad \text{\textcolor{red}{Transition region}} \quad \longleftarrow$$

DVCS not special, look at full set of singlet channels, incl. $J/\psi, \phi, \rho^0, \gamma$!

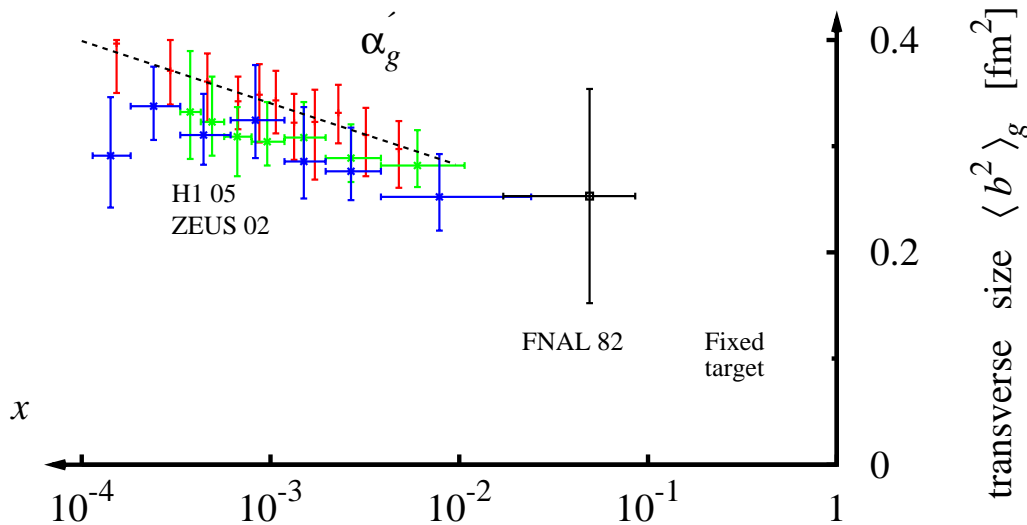Test reaction mechanism: Universality, Q^2–scaling of t–slopes, . . .

Transverse distribution: Gluons

Q^2 —— hard —— J/ψ, ϕ

N —— GPD —— N', Δ_T

α'_g

H1 05
ZEUS 02

FNAL 82   Fixed target

x

10^{-4} 10^{-3} 10^{-2} 10^{-1} 1

transverse size $\langle b^2 \rangle_g$ [fm^2]

0.4

0.2

0

- Transverse spatial distribution from $\gamma^{(*)} + N \to J/\psi + N$

  Reaction mechanism, QCD–based description tested at HERA

  Transverse distribution from *relative* Δ_T dependence

- Interesting observations

  Gluonic transverse radius at $x > 0.1$ smaller than transverse charge radius $\langle b^2 \rangle_g < \langle b^2 \rangle_{\mathrm{charge}}$
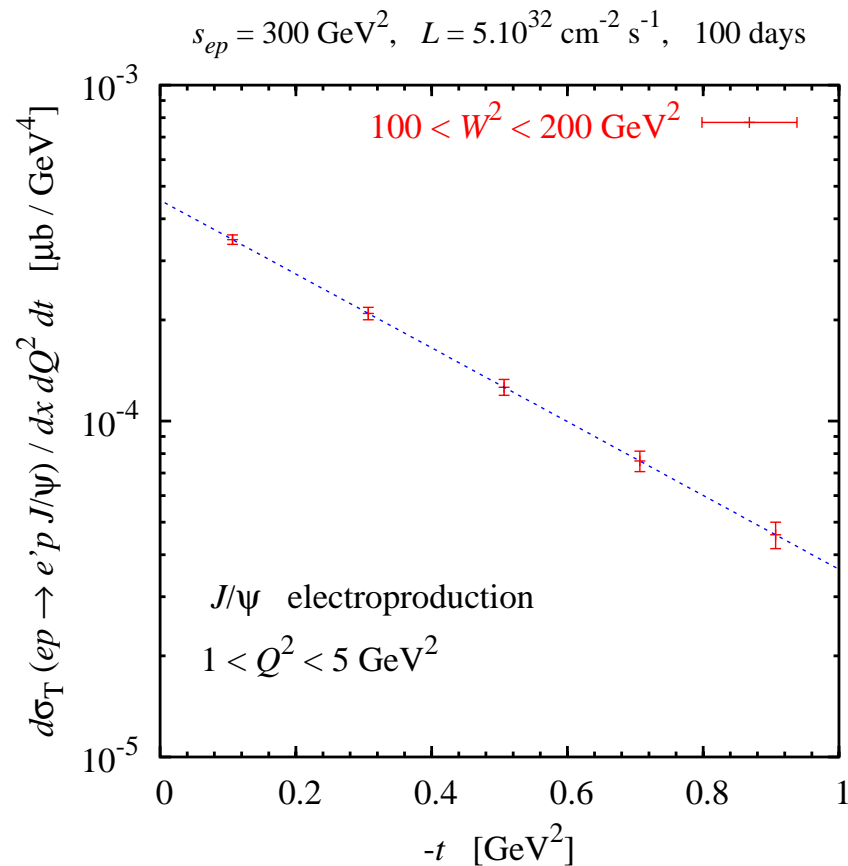
  Increase between $x \sim 0.1$ and 0.01 $\leftrightarrow$ Chiral dynamics?

  Regge–like growth below $x < 0.01$ with slope $\alpha'_g < \alpha'_P = 0.25\,\mathrm{GeV}^{-2}$

Transition region largely unexplored!

COMPASS: Gluons with $J/\psi, \phi$

$s_{ep} = 300 \,\mathrm{GeV}^2, \quad L = 5.10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}, \quad 100 \,\mathrm{days}$

$100 < W^2 < 200\,\mathrm{GeV}^2$

J/ψ electroproduction

$1 < Q^2 < 5\,\mathrm{GeV}^2$

$d\sigma_T\,(ep \to e'p\,J/\psi)\,/\,dx\,dQ^2\,dt \quad [\mu\mathrm{b}\,/\,\mathrm{GeV}^4]$

$-t \quad [\mathrm{GeV}^2]$

Preliminary rate estimate – should be checked!

- COMPASS: Gluon imaging through exclusive J/ψ

   $x > 0.01$: Map unexplored region of non-perturbative gluons!

- Aim for

   Full t–distribution $\to$ Fourier
   Non-exponential? Power–like at $|t| > 1\,\mathrm{GeV}^2$?
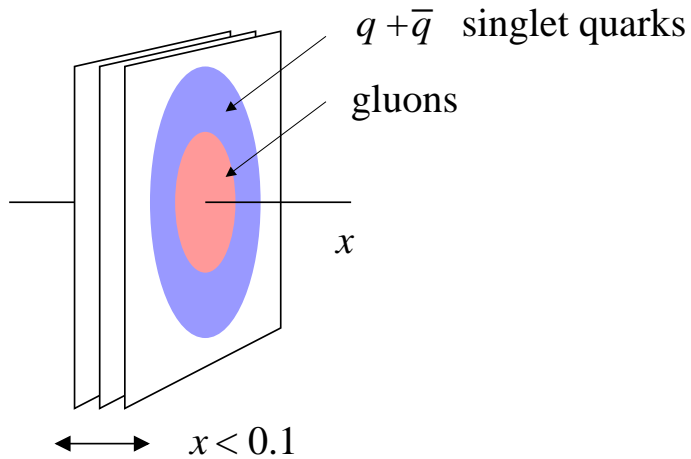
   Leptoproduction, not just photoproduction:
   Test reaction mechanism through Q^2 dependence

- Alt: Exclusive ϕ production

   HERA data show dominance of small–size configurations for $Q^2 > 10\,\mathrm{GeV}^2$

   Test universality through different channels
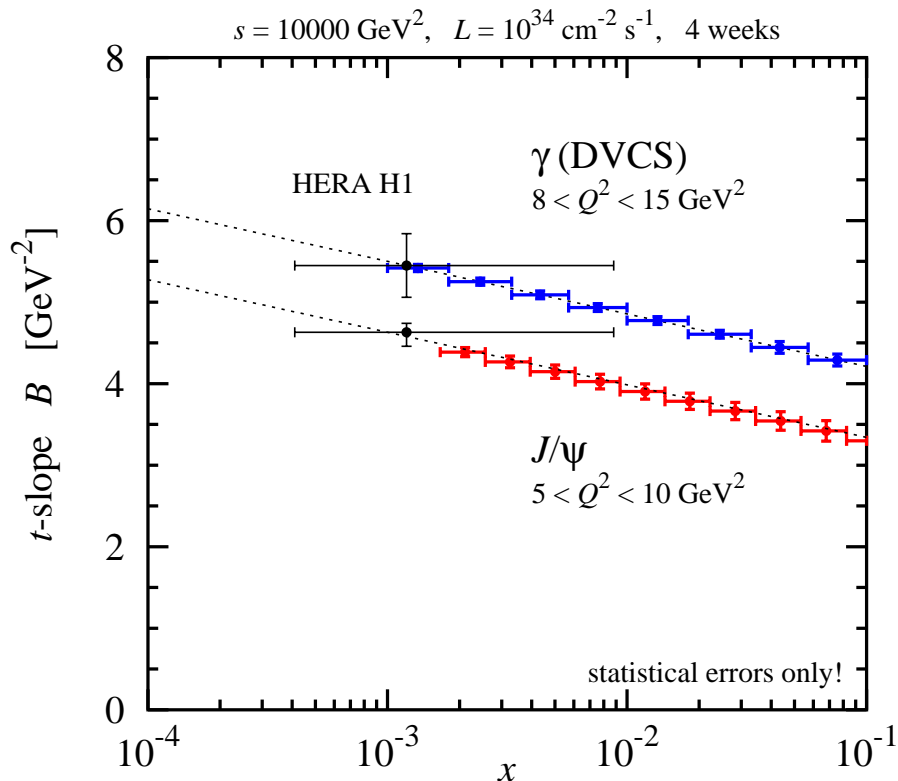
Gluon vs. singlet quark distribution

$q + \bar{q}$ singlet quarks

gluons

x

$x < 0.1$

$s = 10000 \text{ GeV}^2$, $L = 10^{34} \text{ cm}^{-2} \text{s}^{-1}$, 4 weeks

HERA H1

γ (DVCS)
$8 < Q^2 < 15 \text{ GeV}^2$

J/ψ
$5 < Q^2 < 10 \text{ GeV}^2$

t-slope B [GeV^{-2}]

statistical errors only!

x

EIC simulation Sandacz, Hyde, CW − adapt to COMPASS!

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

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

  Dynamical models predict difference:
  Pion cloud, constituent quark picture

  No difference assumed in present
  pp MC generators for LHC!
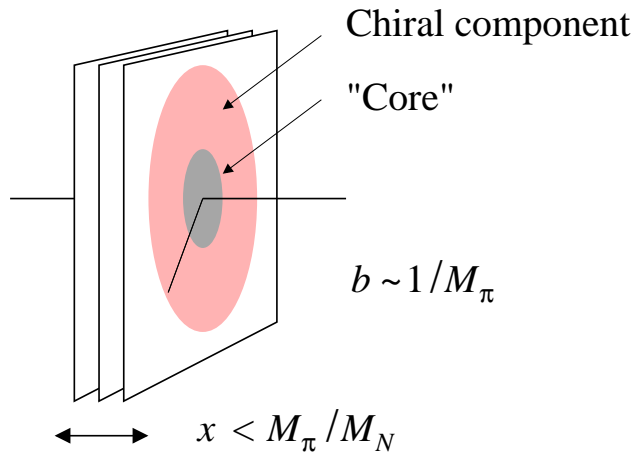
- Gluon size from J/ψ,
  singlet quark size from DVCS

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

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

  Detailed differential images of
  nucleon's partonic structure

Transverse distribution: Chiral component

Chiral component

"Core"

$b \sim 1/M_\pi$

$x < M_\pi / M_N$

$\langle b^2 \rangle_{f,\,\text{chiral}}$ [fm^2]

$f = g$

$u + \bar{u} + d + \bar{d}$

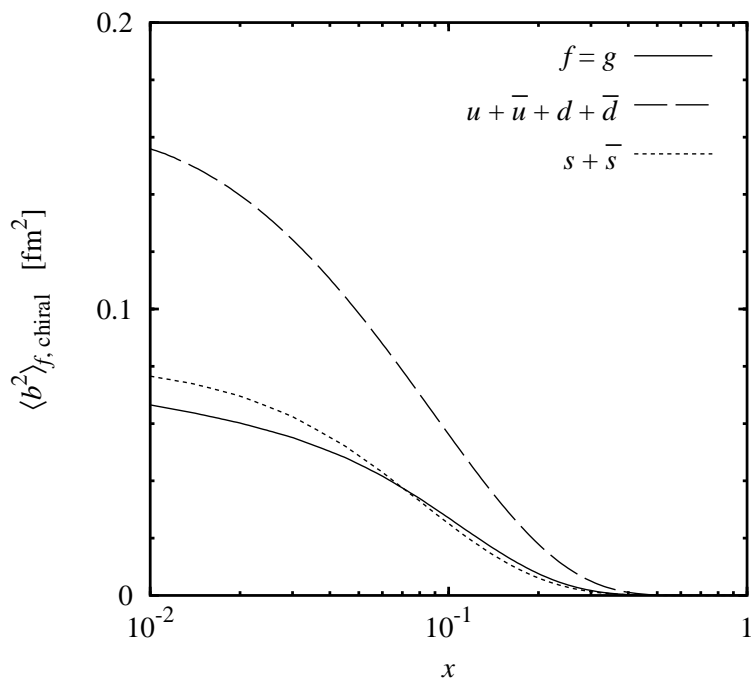$s + \bar{s}$

x

Strikman, CW PRD80:114029,2009

- Large–distance component of PDF at $b \sim 1/M_\pi$ and $x < M_\pi / M_N$ from chiral dynamics: "Pion cloud"
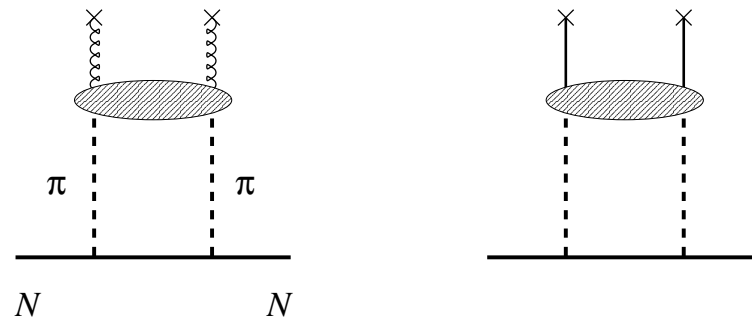
  Model–independent, cf. Yukawa tail
  Strikman, CW 03/09

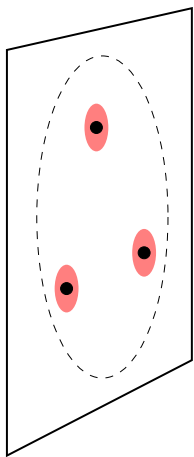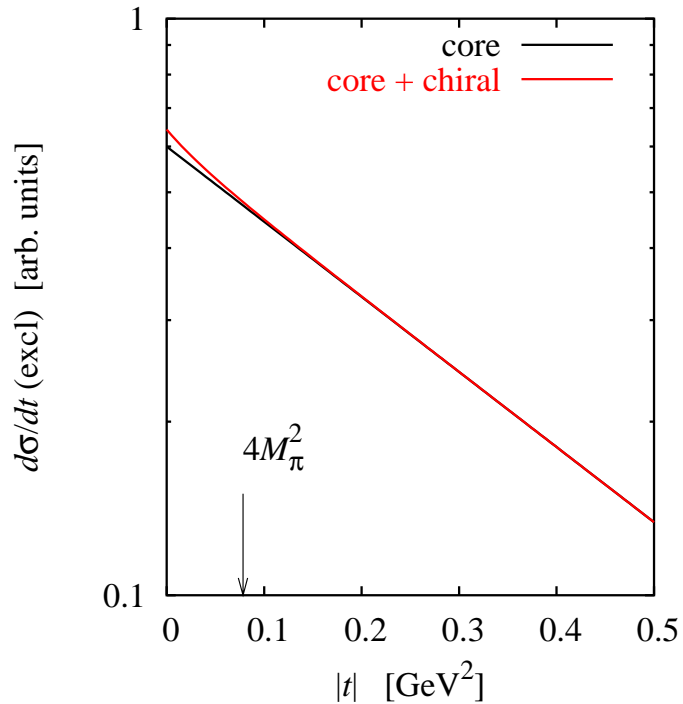 Strong in isoscalar quarks/gluon, suppressed in isovector $\bar{d} - \bar{u}$

- Increase of $\langle b^2 \rangle$ in transition region

  Suggests $\langle b^2 \rangle_{q+\bar{q}} > \langle b^2 \rangle_g$, cf. DVCS $> J/\psi$ slope at HERA!

π π

N N

Transverse distribution: Chiral component

- Can we test it experimentally?

  t–dependence of exclusive $J/\psi, \phi, \gamma$:
  Chiral component at $t < 4M_\pi^2 \sim 0.1\,\text{GeV}^2$

  Deviation from exponential behavior – very challenging!

- Theoretical issues

  Small–t region can have dramatic effect
  on average transverse size $\langle b^2 \rangle$

  Need model of non-chiral core!
  Gluons packaged in "constituent quarks"
  $\leftrightarrow$ QCD vacuum structure

Chiral component: Pion knockout processes

Q^2 ⟶ V

GPD ······· π

π t_π

N N

t_N

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

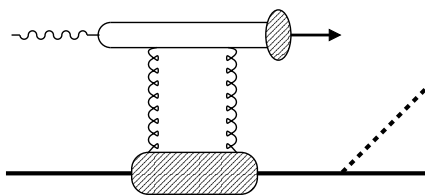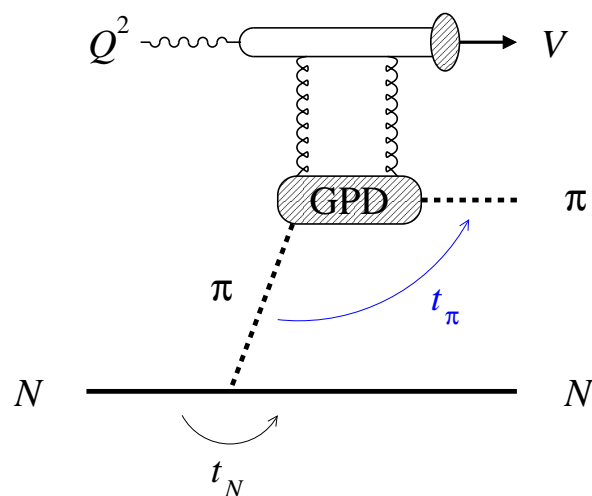 $F_{\pi NN}(t)$ softer than $\mathrm{GPD}_\pi(t)$

- 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!

Meson production: Non-singlet channels

pointlike

Q^2 —— hard —— π, ρ K, K^*

N —— GPD —— p Λ, Σ

$\bar{u}, \bar{d}$

$s, \bar{s}$

x

$x < 0.1$

- Non-singlet channels practically unexplored at $x < 0.1$

  Cross sections drop with x, small

  Reaction mechanism: Transition to small–size regime?

  Energy dependence should change with Q^2:
  Soft: $\alpha'_R \approx 0.9\,\mathrm{GeV}^{-2}$
  Hard: $\alpha'(Q^2)$ expected much smaller
  Where/how does transition occur?

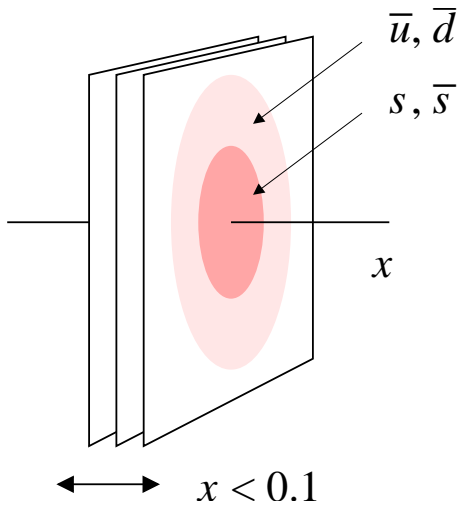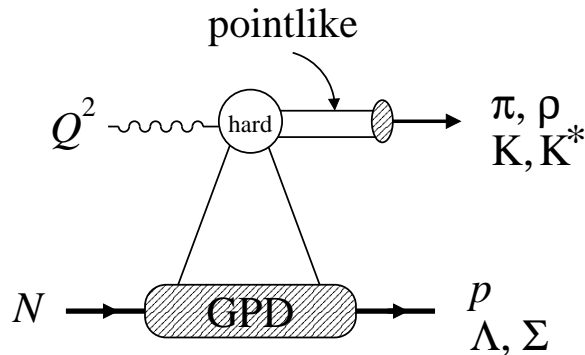 Progress with higher twist in hard amplitudes $\rightarrow$ Kroll

- Could provide valuable information on transverse structure of non-perturbative sea, incl. polarization

  Meson quantum numbers select spin/flavor component of GPD

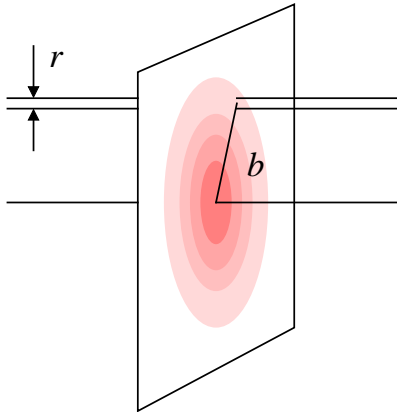 Information about meson wave function: Size, flavor structure

  Even limited data would be very interesting!

Transverse structure in pp@LHC

- Transverse gluon distribution essential ingredient in studies of unitarity limit/saturation at small x
  Kowalski, Teaney; Frankfurt, Strikman + collab; . . .

  Initial conditions for non-linear QCD evolution

  $Q_{\text{sat}} \sim$ gluons/transverse area

- Phenomenology of high–energy pp collisions with hard processes

  Probability for multiple hard processes governed by transverse distribution of partons
  $\rightarrow$ MC generators, pedestal for new physics
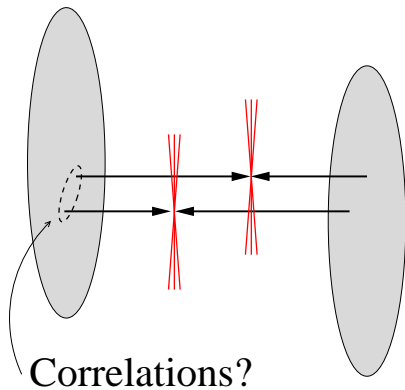 $\rightarrow$ Multiparton correlations?

  Rapidity gap survival in exclusive diffraction $pp \rightarrow p+H+p$
  $x_{1,2} = M_H/\sqrt{s} \sim 10^{-2}$ Frankfurt, Hyde, Strikman, CW 06

  Underlying event structure:
 Centrality, spectator interactions

r

b

Correlations?

Transverse structure at $x \sim 10^{-2}$ essential input!

Summary (tentative)

- Aim to measure all singlet channels: $J/\psi, \phi, \rho^0, \gamma$

  Test reaction mechanism, separate gluons/singlet quarks

- Transverse distribution of gluons/singlet quarks in transition region

  Both small $|t| < 0.1\,\mathrm{GeV}^2$ and large $|t| > 1\,\mathrm{GeV}^2$ interesting
  Chiral component very difficult to identify in t–dependence

- Non-singlet channels $\rho^+, K^*, \pi, \eta, K, \ldots$ completely unexplored

  Transition soft $\leftrightarrow$ hard reaction mechanism?
  Transverse distribution of non-singlet sea (spin/flavor)? t–dependence

- Usefulness for pp@LHC important part of motivation

Supplementary material

Transverse distribution: Change with Q^2
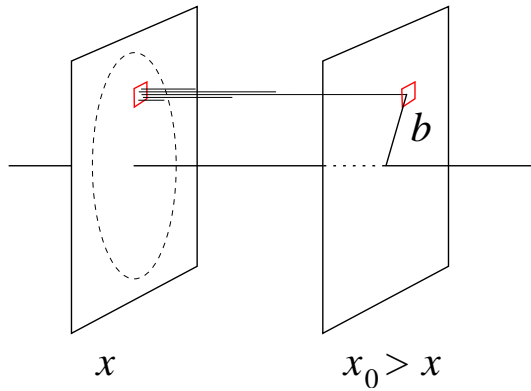
- Transverse distribution of partons changes through DGLAP evolution

  Transverse size decreases with increasing Q^2

  Effective Regge slope α'_g decreases with Q^2

Frankfurt, Strikman, CW, PRD 69, 114010 (2004)