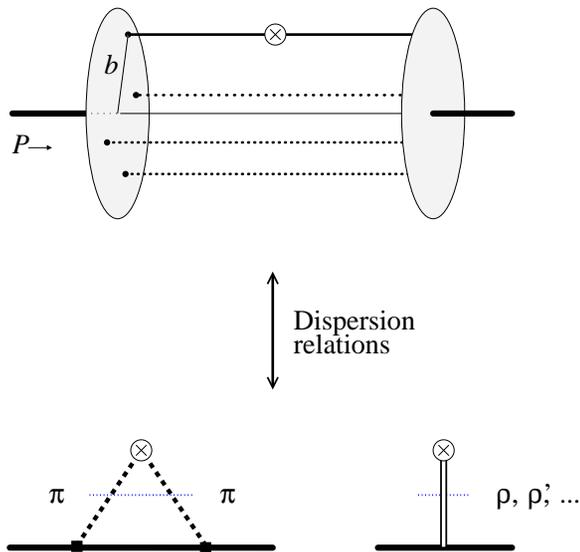


Transverse densities from timelike form factors

C. Weiss (JLab), DIS2011 "Spin physics," 14-Apr-11



- Transverse charge and current densities

Partonic representation of form factors

Spectral representation and filtering property $\sqrt{t} \sim 1/b$

- Nucleon transverse densities

Chiral large-distance component $e^{-m_\pi b}$
from χ PT [Strikman, CW, PRC82 \(2010\) 042201](#)

Spectral analysis: Zooming in on vector mesons ρ, ω

[Miller, Strikman, CW; in preparation](#)

- Pion transverse charge density

Timelike pion form factor from e^+e^- data

Singular charge density at $b \rightarrow 0$:
Pointlike $q\bar{q}$ configurations in pion
[Miller, Strikman, CW, PRD83 \(2011\) 013006](#)

New insights in partonic structure!

Quantify pion cloud, vector meson dominance in QCD!

Study vector meson couplings in t -channel kinematics!

Transverse densities: Partonic representation

- Elastic form factors

$$\text{Local current } \langle N' | J_\mu | N \rangle \sim F_{1,2}(t)$$

$$\text{Transverse momentum transfer } |t| = \Delta^2$$

- Transverse charge density Soper 76, Miller 07

$$\rho(b) = \int \frac{d^2\Delta}{(2\pi)^2} e^{-i\Delta b} F_1(-\Delta^2) \quad \text{2D Fourier}$$

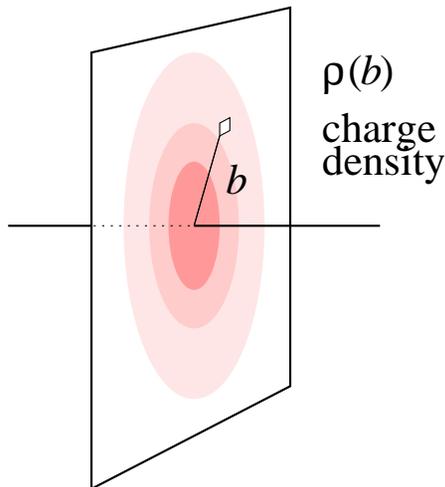
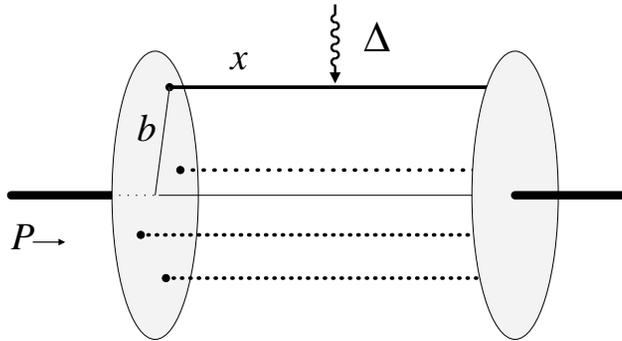
Cumulative charge of constituents at distance b from transverse center-of-mass

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

- Densities from spacelike FF data

Neutron positive at $b \sim 0.5 - 1$ fm
 Contradicts naive picture of $p(\text{center}) + \pi^-(\text{cloud})$ Miller 07

Extension to $N \rightarrow \Delta$, higher-spin systems
Carlson, Vanderhaeghen 07; Lorce et al. 09+



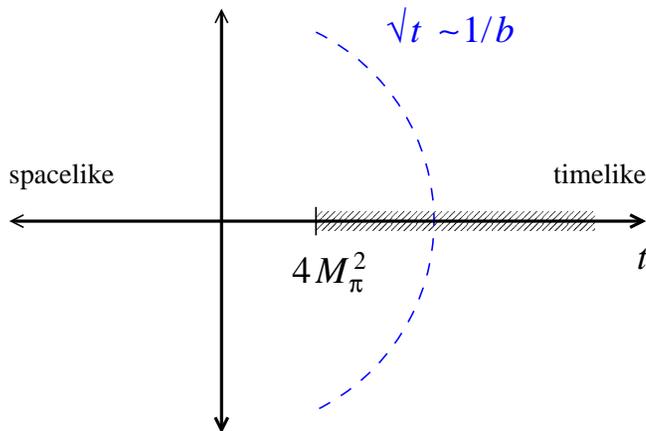
Transverse densities: Dispersion representation

- Dispersion representation of form factor

$$F(t) = \int_{4m_\pi^2}^{\infty} \frac{dt'}{t' - t - i0} \frac{\text{Im } F(t')}{\pi}$$

Spectral function $\text{Im } F(t')$ describes “process”
current \rightarrow hadronic system $\rightarrow N\bar{N}$

Unphysical region: Spectral function from dispersion
analysis, χ PT near threshold, pQCD $t \rightarrow \infty$

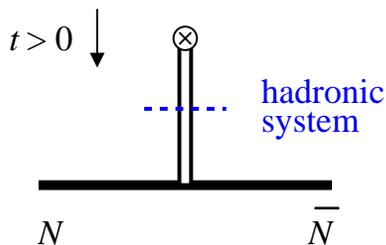


- Transverse density

$$\rho(b) = \int_{4m_\pi^2}^{\infty} \frac{dt}{2\pi^2} K_0(\sqrt{t}b) \text{Im } F(t)$$

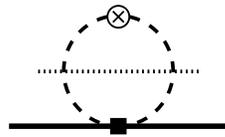
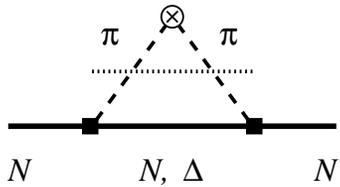
$K_0 \sim e^{-b\sqrt{t}}$ exponential suppression of large t

Distance b selects masses $\sqrt{t} \sim 1/b$: “Filter”
Cf. Borel transformation in QCD sum rules. Strikman, CW 10



Analyticity permits study of large- b asymptotics

Nucleon: Chiral component at large b



- Transverse density at $b \sim 1/M_\pi$ from chiral dynamics Strikman, CW 10

$$\text{Im}F_1(t) \text{ near threshold } t \rightarrow 4M_\pi^2$$

Isovector two-pion exchange leading

Universal, calculable in χ PT
Heavy-baryon expansion does not converge
Becher, Leutwyler 99; Kaiser 03

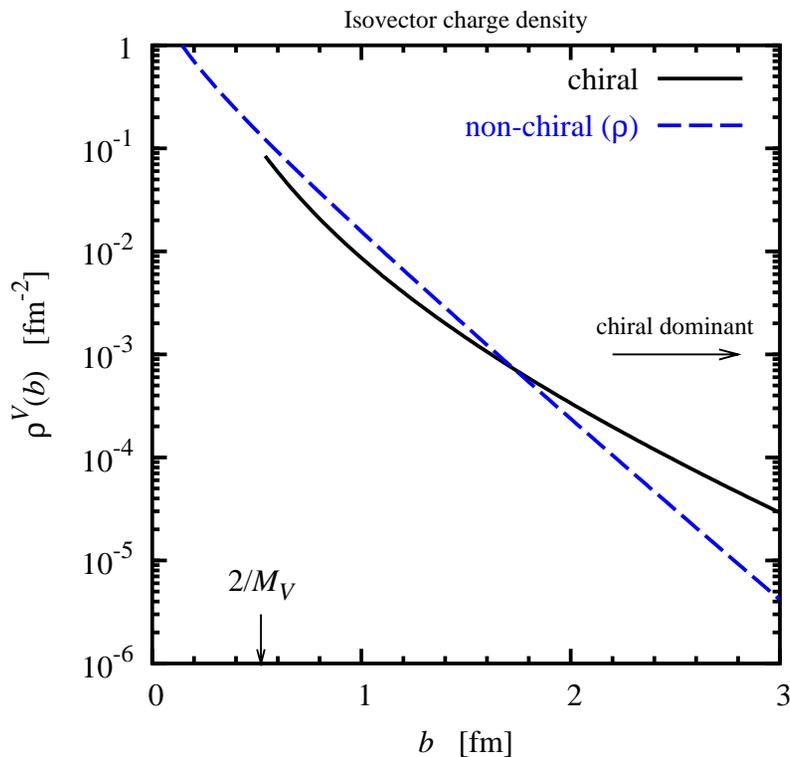
Equivalence of invariant and light-front formulations demonstrated

Δ intermediate states ensure proper N_c -scaling of isovector density

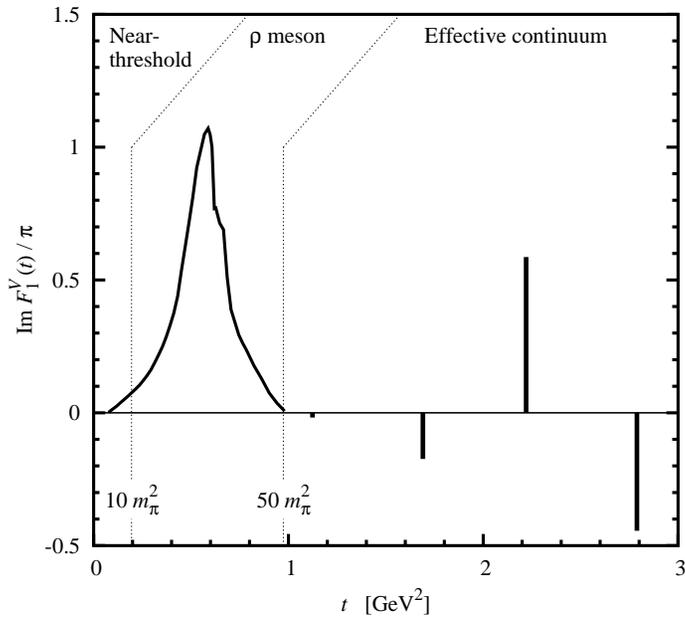
- Chiral component dominates only at distances $b > 2$ fm

Large non-chiral density from ρ exchange

Contradicts traditional notion of “pion cloud” at distances ~ 1 fm



Nucleon: Spectral analysis of transverse densities



- Analyze contribution of spectral mass regions to transverse densities

Model-independent! Miller, Strikman, CW, in preparation

Empirical spectral functions from FF fits

Belushkin, Hammer, Meissner 07

Connect partonic structure with hadronic exchange mechanisms

- Isovector charge density

Near-threshold $\pi\pi$ relevant only at $b > 2$ fm

Intermediate $b = 0.5 - 1$ fm dominated by ρ , with 10 – 15% correction from first ρ'

Perfect “vector dominance,” fully quantitative!

- Isoscalar charge density

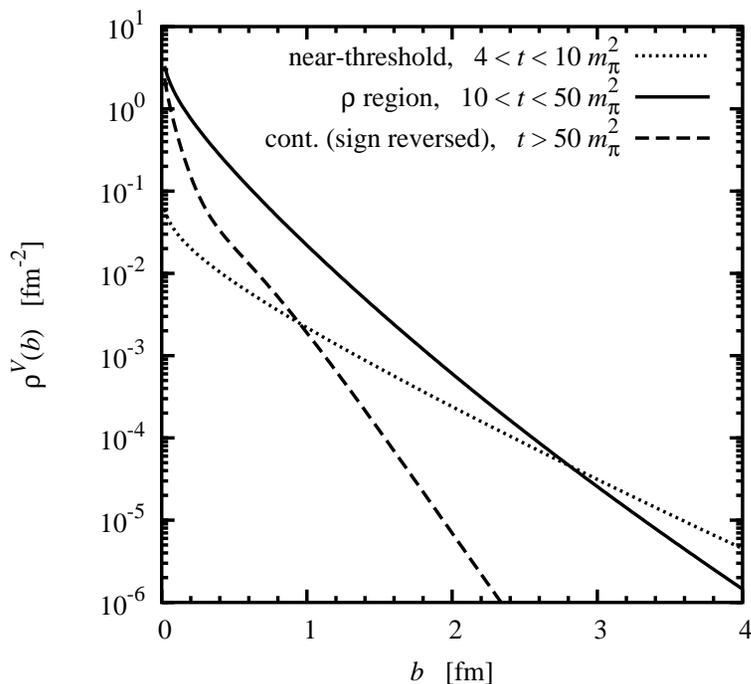
No near-threshold strength, 3π very small

ω dominates at $b \sim 2$ fm

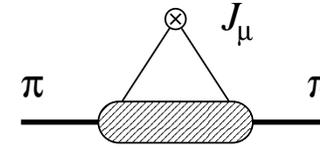
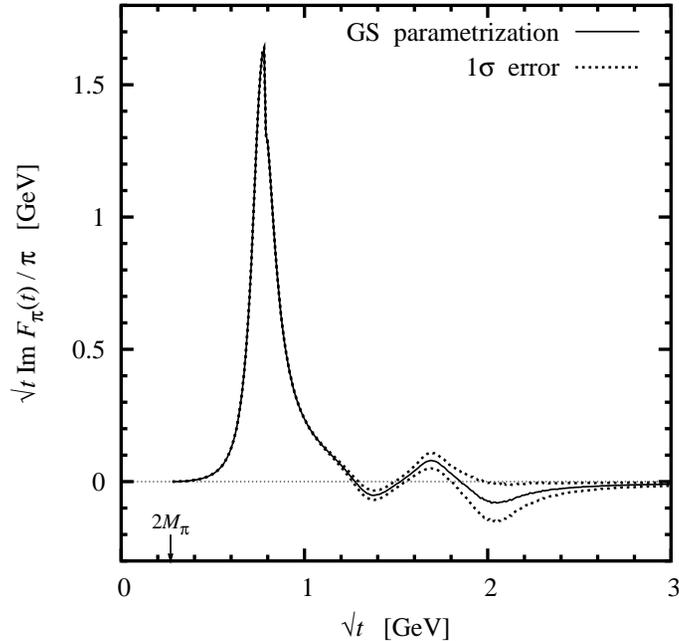
Intermediate $b \sim 1$ fm mostly from ω , with 30% contribution from higher-mass states

Physical origin uncertain: $\phi, K\bar{K}, \pi\rho?$

Related to strangeness in nucleon from PVES at JLab



Pion: Transverse density from timelike data



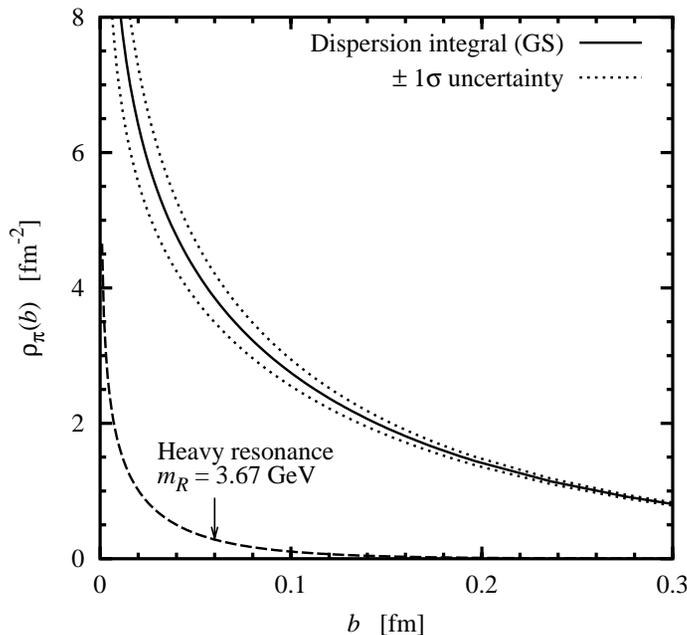
- Spacelike FF poorly known at $|t| > 1 \text{ GeV}^2$
Electroproduction on nucleon, model-dependent. JLab Hall C 6/12 GeV

- Timelike FF from e^+e^- annihilation

$|F_\pi|^2$ from cross secn, phase from models/theory

Resonance-based parametrization from fit to data
Bruch, Khodjamirian, Kuhn 04. CLEO 05 results not included.

- Transverse density from dispersion integral
Miller, Strikman, CW 10

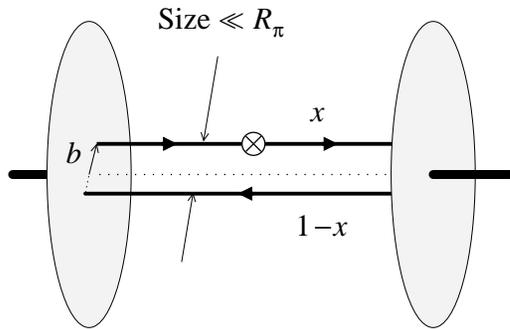


$$\rho_\pi(b) = \int_{4m_\pi^2}^{\infty} \frac{dt}{2\pi^2} K_0(\sqrt{tb}) \text{Im } F_\pi(t)$$

Fully calculable, precise, error estimates

Singular charge density at center of pion

Pion: Partonic interpretation



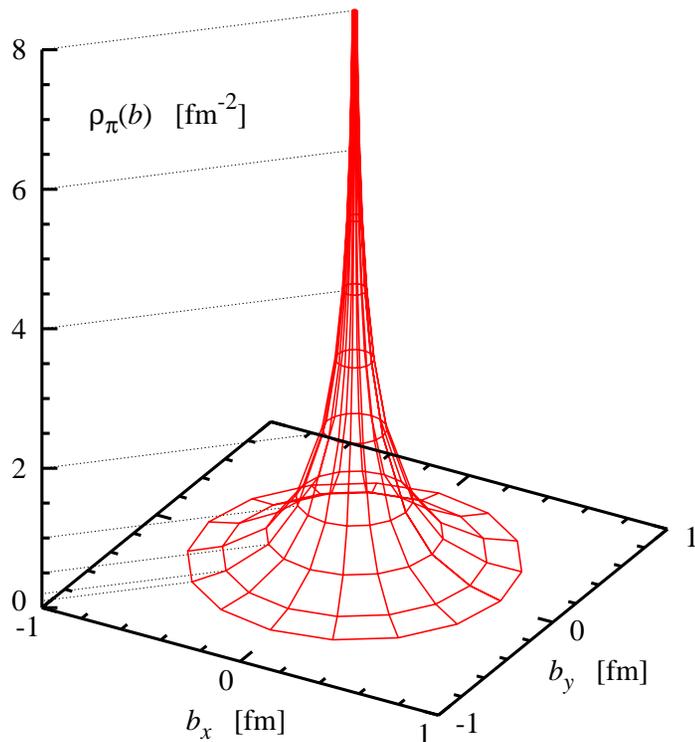
- Singular charge density at center due to point-like configurations in pion wave function

Configs of size $r \ll R_\pi$, mostly elementary $q\bar{q}$

Observable in other high-momentum transfer processes: $\gamma^*\gamma \rightarrow \pi^0$, $\pi + A \rightarrow 2 \text{ jets}, \dots$
 Universal property

Large-size configurations with $x \rightarrow 1$ at scales $Q^2 > 1 \text{ GeV}^2$ cannot account for empirical charge density at $b \rightarrow 0$
 Miller, Strikman, CW 10

Detailed modeling with light-cone wave functions Miller, Strikman; in progress



- 2D image of fast-moving pion

First accurate transverse image based on data!

Summary

- Transverse densities connect partonic structure with hadronic spectrum
 - Fully quantitative, consistent with QCD
 - New approach to duality
- Dispersion integral for $\rho(b)$ samples spectral function at energies $\sqrt{t} \sim 1/b$
 - Systematic study of exchange mechanisms
 - Mathematical properties: Asymptotic behavior, error analysis, . . .
- Nucleon charge density at intermediate distances $b = 0.5 - 1.5$ fm governed by vector mesons
 - Chiral component dominant only at $b > 2$ fm
 - Origin of isoscalar strength beyond ω still unclear
- Pion charge density from timelike form factor data
 - Precise 2D image with controlled accuracy
 - Singular charge density at center attributed to pointlike $q\bar{q}$ configurations