Large–t exclusive processes and the size of the constituent quark

Ch. Weiss (JLab), Hall C Workshop, 1/6/06

Non-perturbative short–distance scale

$\rho \sim 0.3\,\text{fm}$

Range of chiral symmetry breaking interactions

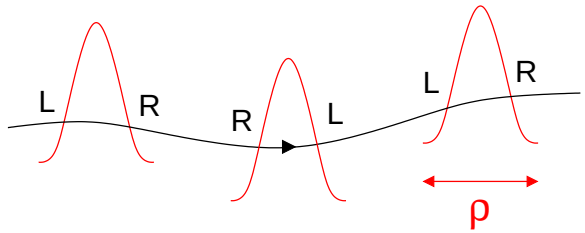
"Size" of constituent quark

} "Vacuum structure" of QCD

- Two–scale model of pion form factor
- Partonic fomulation: GPD's
- WACS, proton form factor (comments)

[A. Afanasev, CW; in progress]

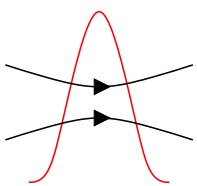
- Chiral symmetry breaking in QCD [Shuryak 82; Diakonov, Petrov 84, ...]



Quarks propagate through
vacuum gluon fields
of size $\rho \ll 1$ fm (instantons)

$$\rho^{-2} \sim \frac{\langle 0|\bar{\psi}_L \nabla^2 \psi_R|0\rangle}{\langle 0|\bar{\psi}_L \psi_R|0\rangle} \equiv \frac{m_0^2}{2}$$

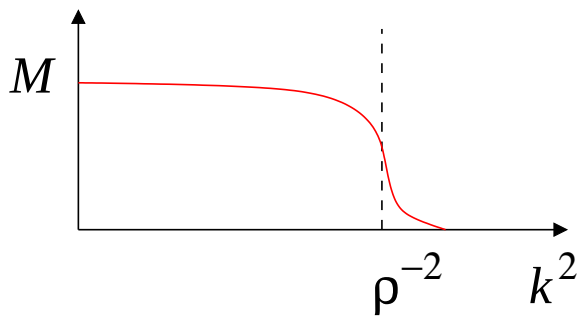
Gauge invariant "measure" of size
Lattice: $m_0^2 > 1\,\text{GeV}^2$
[Kremer et al. 87; Doi et al. 03]



Vacuum fields induce
short–range interaction between quarks
(valence and sea)

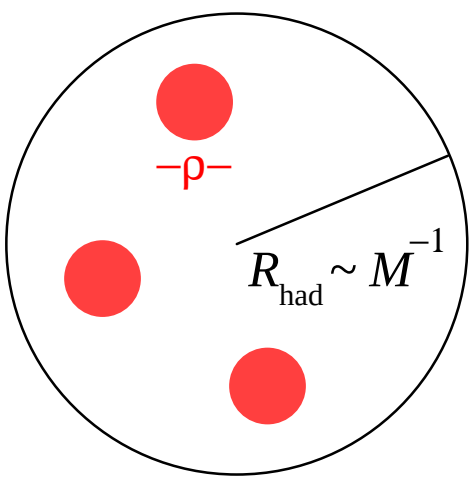
Short–distance scale $\rho \ll R_{\text{hadron}}$ related to chiral symmetry breaking

- Constituent quark picture



$M \approx 350\,\text{MeV}$ constituent quark mass

$\rho^{-1} \gg M$ constituent quark "size"

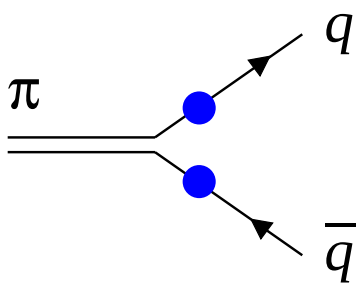


– Two–scale picture of hardon structure

– Long–wavelength characteristics of hadrons not explicitly sensitive to CQ size (important only $\rho \ll R_{\text{had}}$)

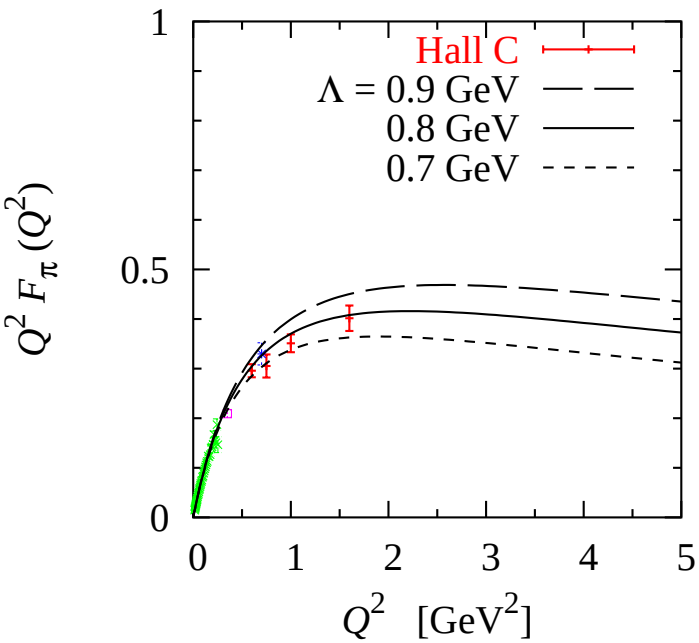
– High–t processes may directly feel short–distance scale ρ

- Two–scale model of pion [cf. Diakonov, Petrov 86]



Dynamical quark mass M $\leftrightarrow$ Size of bound state

Form factor suppresses virtualities $k^2 > \Lambda^2$ $\leftrightarrow$ "Size" of const. quark ($\rho \sim \Lambda^{-1}$)

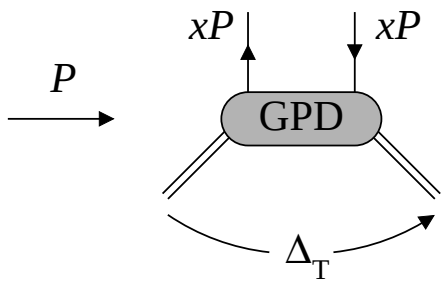


[Afanasev, CW 05]

- Charge radius determined by mass $\langle r^2 \rangle_\pi \propto M^{-2}$
- Form factor at $Q^2 \geq \Lambda^2$ governed by constituent quark size
- "Asymptotic" behavior in model: $F_\pi \propto \frac{\Lambda^4}{Q^4} \log(Q^2/\Lambda^2)$

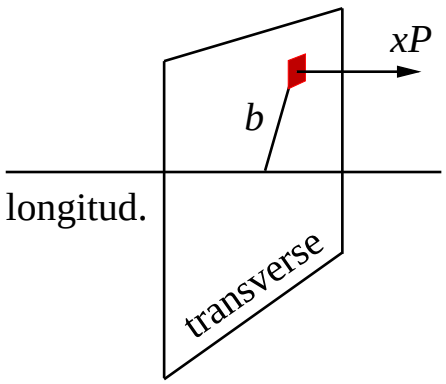
[Instanton vacuum Faccioli et al. 02]

- Partonic formulation: Impact parameter representation [Burkardt 02]



$$H(x,t) \;=\; \int d^2b\, e^{-i\vec{\Delta}_\perp\cdot\vec{b}}\, f(x,b)$$

Spatial dist'n of quarks in transverse plane



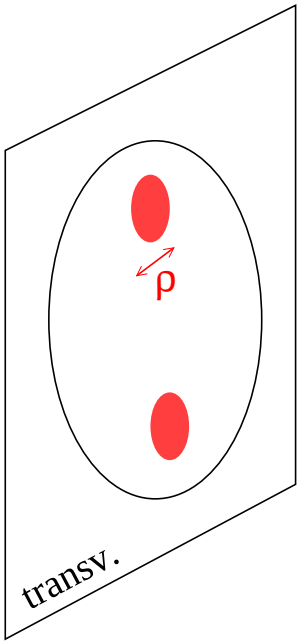
$$F_\pi(t) \;=\; \int dx \int d^2b\, e^{-i\vec{\Delta}_\perp\cdot\vec{b}}\, f(x,b)$$

Large t $\quad\leftrightarrow\quad$ Small b

Impact parameter representation of form factor

Q: Which x give dominant small–b configurations at large t?

- Constituent quark picture in transverse space

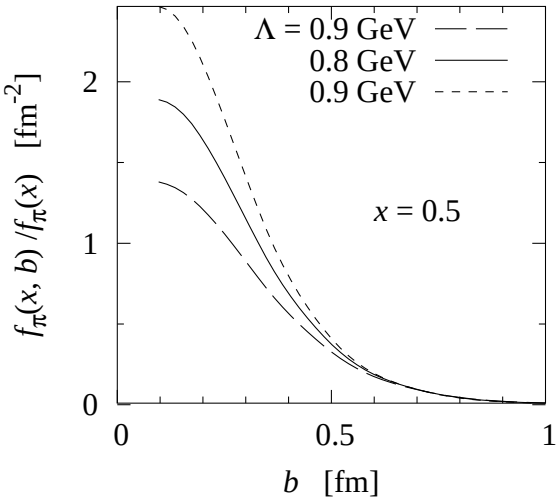


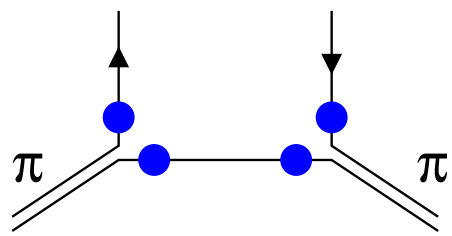
Constituent quarks as
quark–gluon correlations
of transverse size ρ
in hadron wave function

Possibilities for small–b configurations

$$\left.\begin{array}{l} - \text{ Average } x\text{, small } b \\ \\ - \ x \to 1 \end{array}\right\} \begin{array}{l}\text{Affected by} \\ \text{scale } \rho\end{array}$$

- Two–scale model of pion: b–dependent quark distribution

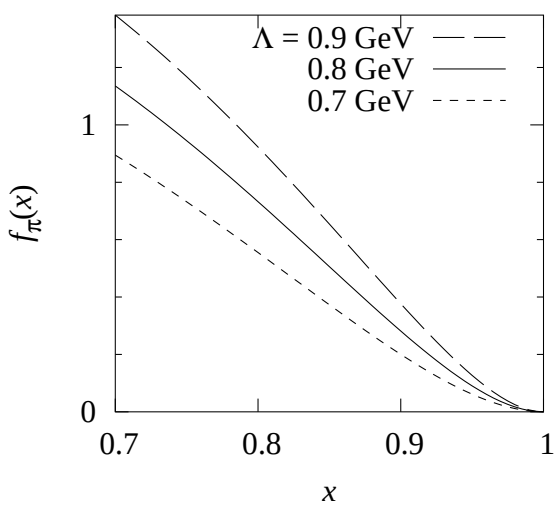




Effect of form factors
(finite size of const. quark):

– Suppress quark density at small b
  for average x

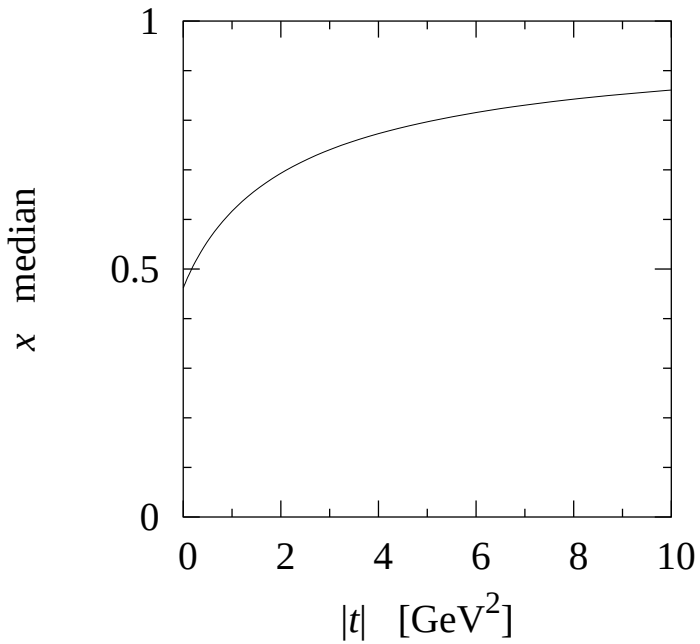
– Suppress quark density at $x \to 1$



[Afanasev, CW 05]

[see also: Mukherjee, Pauli, Radyushkin 03]

- Effective x in pion form factor



  - Form factor at $|t| \sim$ few GeV^2 still determined by moderate x values

  - Region $x \to 1$ (Feynman mechanism) becomes dominant only for $\log \frac{|t|}{\Lambda^2} \gg 1$

- Proton form factor: Spectator system more complex!

$N_c = 3$ "Diquark"	very different $\longleftrightarrow$	$N_c \to \infty$ mean field (soliton)

[Faccioli, Shuryak 02: Small–size diquark ($\sim \rho$) from instanton vaccum]

- Wide–angle Compton scattering [Diehl et al. 97; Radyushkin 98]
  - Scale ρ determines maximum quark virtuality (k^2) in hadrons: "Handbag dominance" justified for $\rho^{-2}/|t| \ll 1$ (small parameter!)
  - Consistent theory requires higher–twist contributions (e.m. gauge invariance)

- Other manifestations of short–distance scale ρ
  ("Size" of constituent quark)

  - Higher–twist corrections in unpol/pol DIS:
    Twist–4 $\sim \dfrac{\rho^{-2}}{Q^2}$ [Sidorov, CW 04]

  - High–energy pp collisions with
    multiple hard scattering processes:
    Parton–parton correlations in transverse position
    [Frankfurt, Strikman, CW 04]

Summary

- Short–distance scale $\rho \sim 0.3\,\text{fm}$
  due to chiral symmetry breaking in QCD

  "Size of constituent quark"

- Two–scale model of pion structure:
  Form factor at $|t| \sim$ few GeV^2
  governed by scale ρ

- Proton form factor: Theory much more challenging!
  . . . "Size" of diquark correlations?