Short range structure of the Pion?

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- What can we say about the pion structure?
- Pion decays weakly $\rightarrow u \bar{d}$ component at very close separations
- Do such components dominate high momentum transfer exclusive reactions?
- If yes, then color transparency (CT) occurs
- There is evidence for color transparency
Why PLC?

At high enough $Q$ an exclusive interaction occurs if the transverse size of the hadron is smaller than the equilibrium size.

Perturbative reasoning—also non-perturbative

Momentum of exchanged gluon $\sim Q$, separation $\sim 1/Q$

- At high enough $Q$ an exclusive interaction occurs if the transverse size of the hadron is smaller than the equilibrium size.
- Perturbative reasoning—also non-perturbative

Hard Gluon Exchange

Large $Q$
Why not PLC?

e-p scattering

Feynman mechanism

Transverse size not affected - no PLC

Instead blob-like configuration - BLC

Interesting dynamical question about QCD - do PLC exist and participate?
\[ \pi + N(A) \rightarrow \text{“2 high transverse momentum jets”} + N(A) \]

The E-791 (FNAL) data \( E_{\text{inc}}^{\pi} = 500 \text{GeV} \) (D. Ashery et al, PRL 2000)

\[ \heartsuit \text{ Coherent peak is well resolved:} \]

\[ \heartsuit \heartsuit \text{ Observed A-dependence } A^{1.61 \pm 0.08} \quad [C \rightarrow Pt] \]

FMS prediction \( A^{1.54} \quad [C \rightarrow Pt] \) for large \( k_t \) & extra small enhancement for intermediate \( k_t \).

For soft diffraction the Pt/C ratio is \( \sim 7 \) times smaller!!
Measurement of Nuclear Transparency for the $A(e, e'\pi^+)$ Reaction


Solid Dashed
Glauber, Glauber +CT
LMS
prc74,018201
dot-dashed, dotted
CosynPRC74,062201

$\pi - A$ total cross section

Solid-Glauber
Point-like configurations (PLC) and Color Transparency (CT)

- PLC exist
- CT Seen at FermiLab energy
- Maybe seen at JLab energy, need 12 GeV
What is charge density of the pion?

- How often is pion in PLC?
- How often is pion in BLC?
- Model-independent Transverse charge density

Probability that quark at \( b \) from CTM has momentum fraction \( x \):

\[
\rho(x, b) = \int dx \rho(x, b)
\]

\[
\rho(b) = \int \frac{d^2q}{(2\pi)^2} F(\frac{Q^2}{2}) e^{-i\mathbf{q} \cdot \mathbf{b}},
\]

\( b \) is distance from center of transverse momentum.
Pion Transverse Charge Density

\[ F_\pi(Q^2) = \frac{1}{1 + R^2 Q^2 / 6}, \]

\[ \rho_\pi(b) = \frac{3 K_0(\sqrt{6b}/R)}{\pi R^2} \]

Singular - varies as \( \log(b) \)
small \( b \), \( \log(\log(b)) \) in pQCD

Dashed- monopole fit, solid rel. cqms Huang

Pion transverse charge density from timelike form factor data

G. A. Miller, M. Strikman, and C. Weiss

\[ F_\pi(t) = \frac{1}{\pi} \int_{4m_\pi^2}^\infty dt' \frac{ImF_\pi(t')}{t' - t + i\epsilon}. \]

Use this expression in equation for transverse density.

\[ \rho(b) = \frac{1}{2\pi} \int_{4m_\pi^2}^\infty dt K_0(\sqrt{tb}) \frac{ImF_\pi(t)}{\pi}. \]

Low \( t' \) dominates except for very small values of \( b \)

Modeling the pion and kaon form factors in the timelike region

C. Bruch\textsuperscript{1}, A. Khodjamirian\textsuperscript{2,a}, J.H. Kühn\textsuperscript{1} \hspace{1cm} Eur. Phys. J. C 39, 41–54 (2005)

\begin{align*}
\sqrt{\text{Im} F_\pi(t)} / \pi \text{ [GeV]} & \quad 2 \quad 2m_\pi \\
0 & \quad 1 & \quad 0 \\
0 & \quad 1 & \quad 2 & \quad 3 \\
\text{t}^{1/2} \text{ [GeV]} & \\
\end{align*}

Parametrization (GS) \hspace{1cm} \pm 1\sigma \text{ error}

\text{MSW PRD83,013006}
\( \rho_\pi(b) \) is known for \( b > 0.1 \) fm

\(~20\%\) of probability for \( b < 0.1 \) fm
Two ways to get small \( b \):
\[ r = \text{separation}, \quad b = r(1-x) \]

- Can have small \( r \) or large \( x \)
- If \( x \) is not near 1, small \( r \) and small \( b \) have same meaning so pion has PLC
- In general don’t expect much prob for \( x \) near 1
- Suppose Feynman mechanism dominates, form factor arises from \( x \) near 1: how much of transverse charge density occurs at small \( r \)? Does pion have PLC or not? Can small \( b \) come from LARGE \( r \)?
Model with Feynman mechanism -updated
Isgur Llwellyn Smith NPB317,526

\[ \Psi(x, k_\perp) = \sqrt{6x(1-x)} e^{-\frac{k_\perp^2}{2\beta^2}} (\pi\beta^2)^{-1/2} \]

\[ Q^2 F_\pi[Q^2] \]

\[ \beta \text{ Fit to Jlab at 2.5 GeV}^2 \]

\[ \text{Integrand}[Q^2] \]

\[ x \text{ nears 1} \]

\[ F_\Pi/LBracket1 Q^2/RBracket1 \]

\[ \frac{1}{2} \]

\[ 24 \]

\[ 9 \]

\[ 4 \]

\[ 1 \]
Define conditional probability: contributions to $\rho$, small $b$, large $r$, $r > r_0$

Use $r = b/(1 - x)$, $x \geq 1 - b/r_0$

$$\rho(b|r > r_0) = \int_{1-b/r_0}^{1} \frac{dx}{(1-x)^2} \tilde{\Psi}^2(x, r = \frac{b}{1-x})$$

small $b$ does not correspond to large $r$!
Summary

- Weak decay of pion says pion must have a non-zero point like configuration PLC
- Pionic color transparency and pion elastic electromagnetic form factor indicate that the PLC is substantial
- Small b corresponds to small r, even with Feynman mechanism
- ~20% of probability occurs for b<0.1 fm