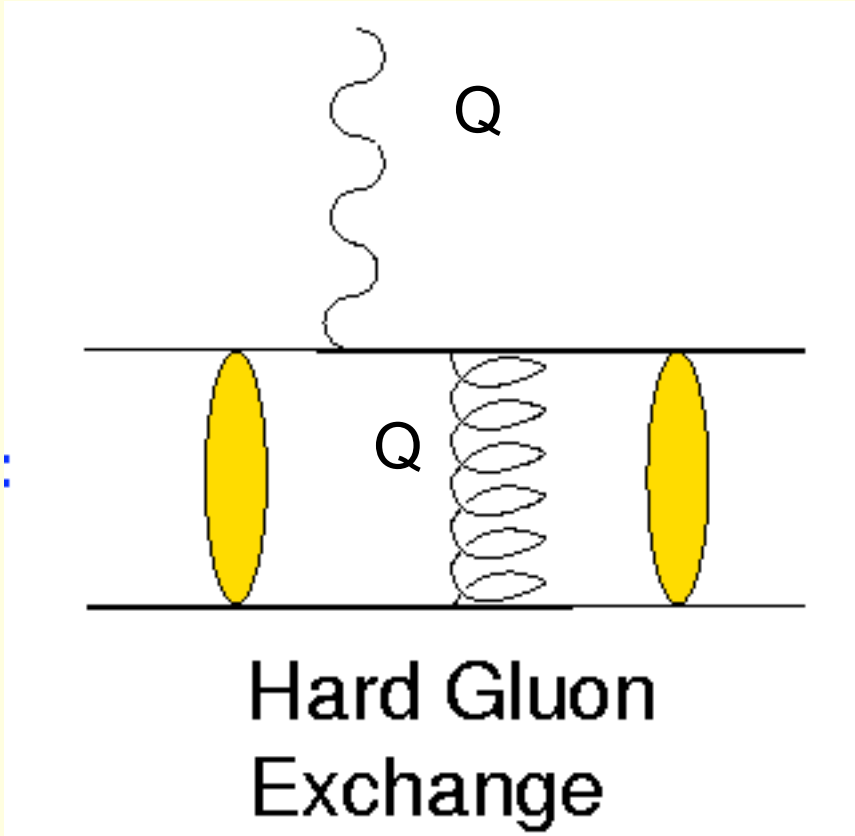
Short range structure of the Pion?

Gerald A. Miller, U. of Washington

- What can we say about the pion structure?
- Pion decays weakly $\longrightarrow$ $u\,\bar{d}$ 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 ?



Large Q

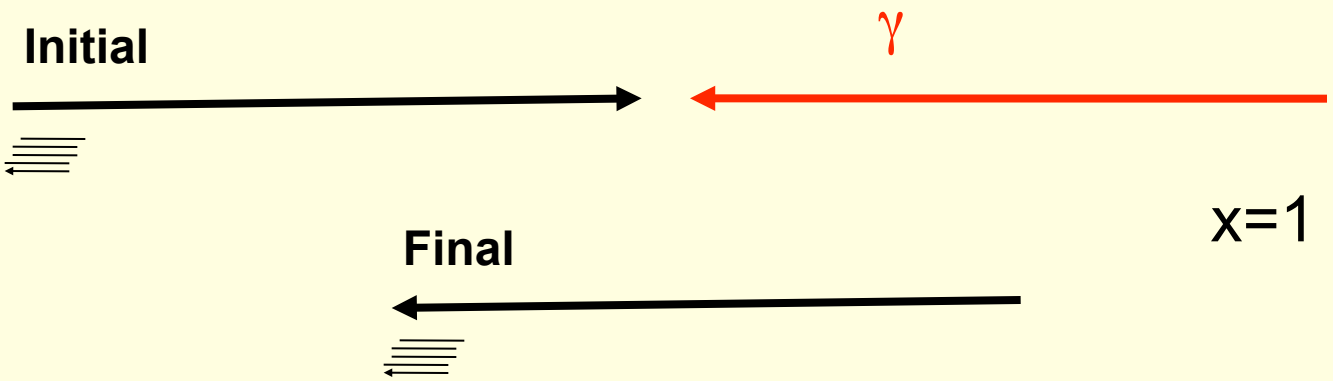
Momentum of exchanged gluon ~Q, separation ~1/Q

- 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

Why not PLC ?

e-p scattering

Feynman mechanism



Transverse size not affected –no PLC

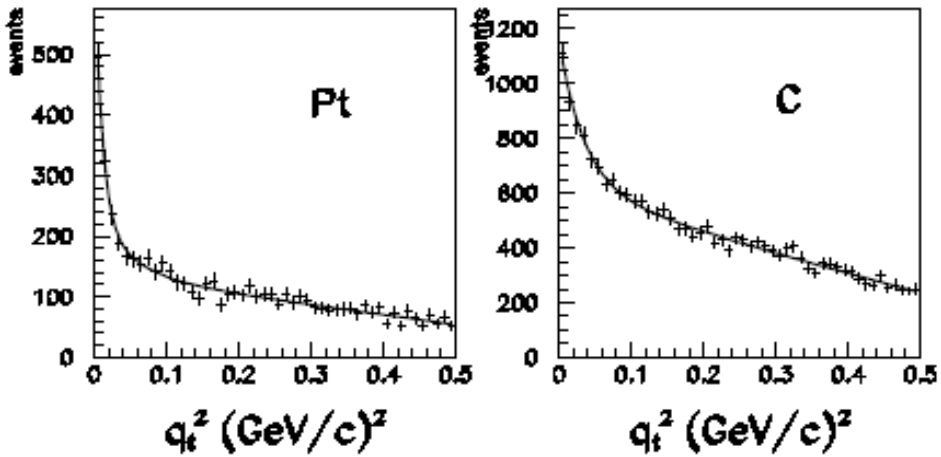
Instead blob-like configuration-BLC

Interesting dynamical question about QCD –do PLC exist and participate?

$\pi + N(A) \to$ "2 high transverse momentum jets" $+ N(A)$

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

♡ Coherent peak is well resolved:



♡♡ Observed A-dependence $A^{1.61\pm0.08}$ $[C \to Pt]$

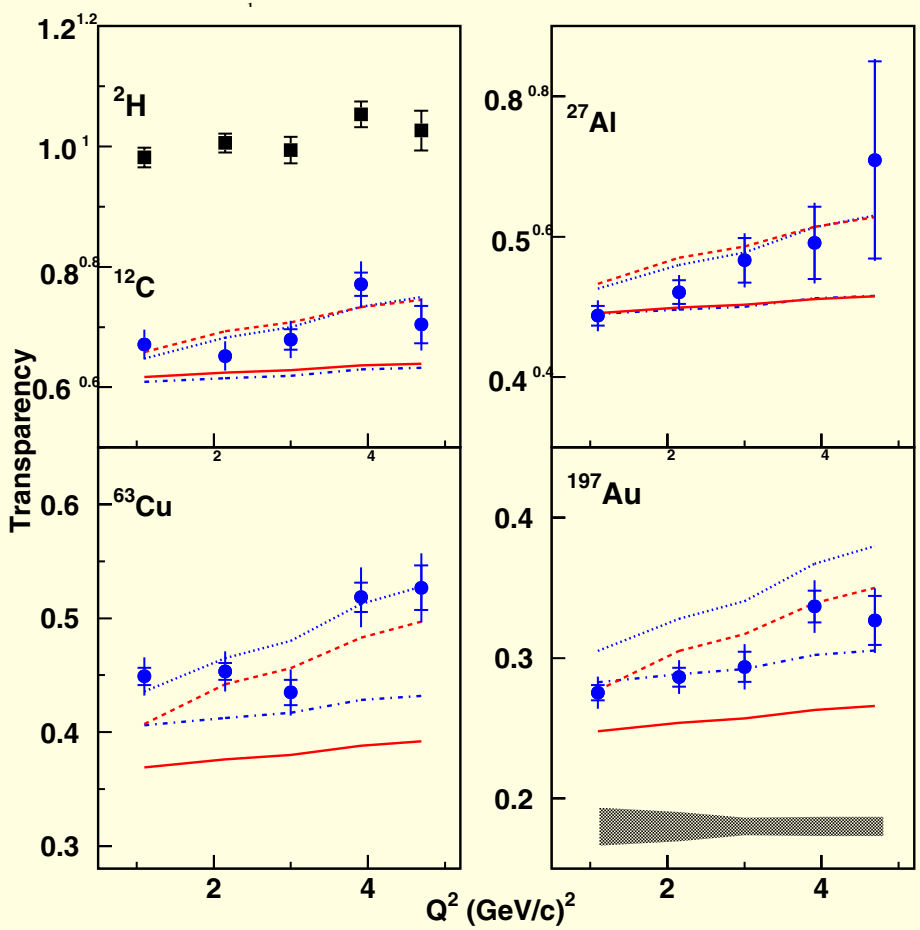
FMS prediction $A^{1.54}$ $[C \to Pt]$ for large k_t & extra small enhancement for intermediate k_t.

For soft diffraction the Pt/C ratio is ~ 7 times smaller!!

PRL 99, 242502 (2007) PHYSICAL REVIEW LETTERS week ending 14 DECEMBER 2007

Measurement of Nuclear Transparency for the $A(e, e'\pi^+)$ Reaction

B. Clasie,[1] X. Qian,[2] J. Arrington,[3] R. Asaturyan,[4] F. Benmokhtar,[5] W. Boeglin,[6] P. Bosted,[7] A. Bruell,[7] M. E. Christy,[8] E. Chudakov,[7] W. Cosyn,[9] M. M. Dalton,[10] A. Daniel,[11] D. Day,[12] D. Dutta,[13,2] L. El Fassi,[3] R. Ent,[7] H. C. Fenker,[7] J. Ferrer,[14] N. Fomin,[12] H. Gao,[1,2] K. Garrow,[15] D. Gaskell,[7] C. Gray,[10] T. Horn,[5,7] G. M. Huber,[16] M. K. Jones,[7] N. Kalantarians,[11] C. E. Keppel,[7,8] K. Kramer,[2] A. Larson,[17] Y. Li,[11] Y. Liang,[18] A. F. Lung,[7] S. Malace,[8] P. Markowitz,[6] A. Matsumura,[19] D. G. Meekins,[7] T. Mertens,[20] G. A. Miller,[17] T. Miyoshi,[11] H. Mkrtchyan,[4] R. Monson,[21] T. Navasardyan,[4] G. Niculescu,[14] I. Niculescu,[14] Y. Okayasu,[19] A. K. Opper,[18] C. Perdrisat,[22] V. Punjabi,[23] A. W. Rauf,[24] V. M. Rodriquez,[11] D. Rohe,[20] J. Ryckebusch,[9] J. Seely,[1] E. Segbefia,[8] G. R. Smith,[7] M. Strikman,[25] M. Sumihama,[19] V. Tadevosyan,[4] L. Tang,[7,8] V. Tvaskis,[7,8] A. Villano,[26] W. F. Vulcan,[7] F. R. Wesselmann,[23] S. A. Wood,[7] L. Yuan,[8] and X. C. Zheng[3]



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

G A Miller, Ann.Rev.Nucl.Part.Sci. 60 (2010) 1-25

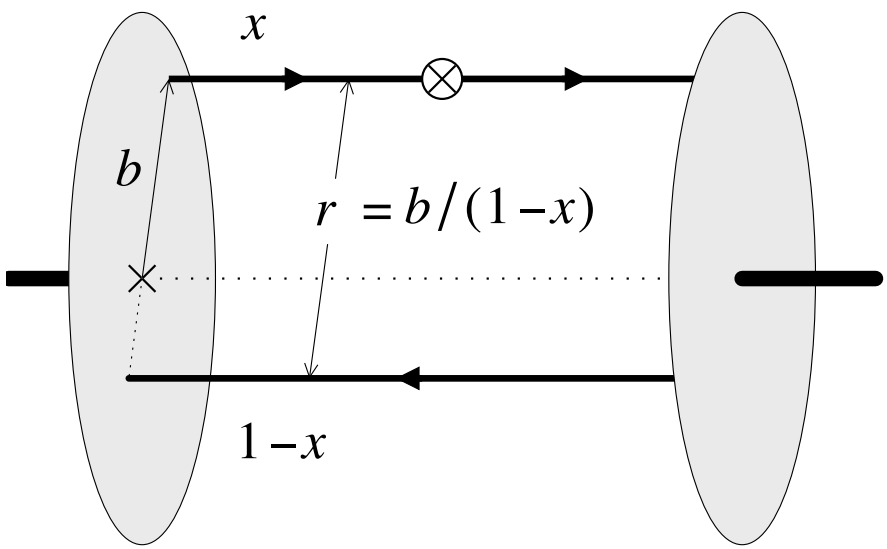
G A Miller Phys. Rev.C79 (2009)055204
Miller, Strikman Weiss **Phys.Rev. D83 (2011) 013006**

Impact parameter dependent GPD Burkardt

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

$$\rho(b) = \int dx \rho(x,b) \qquad \rho(b) = \int \frac{d^2q}{(2\pi)^2} F_\pi(Q^2 = \mathbf{q}^2) e^{-i\mathbf{q}\cdot\mathbf{b}}$$

b is distance from center of transverse momentum



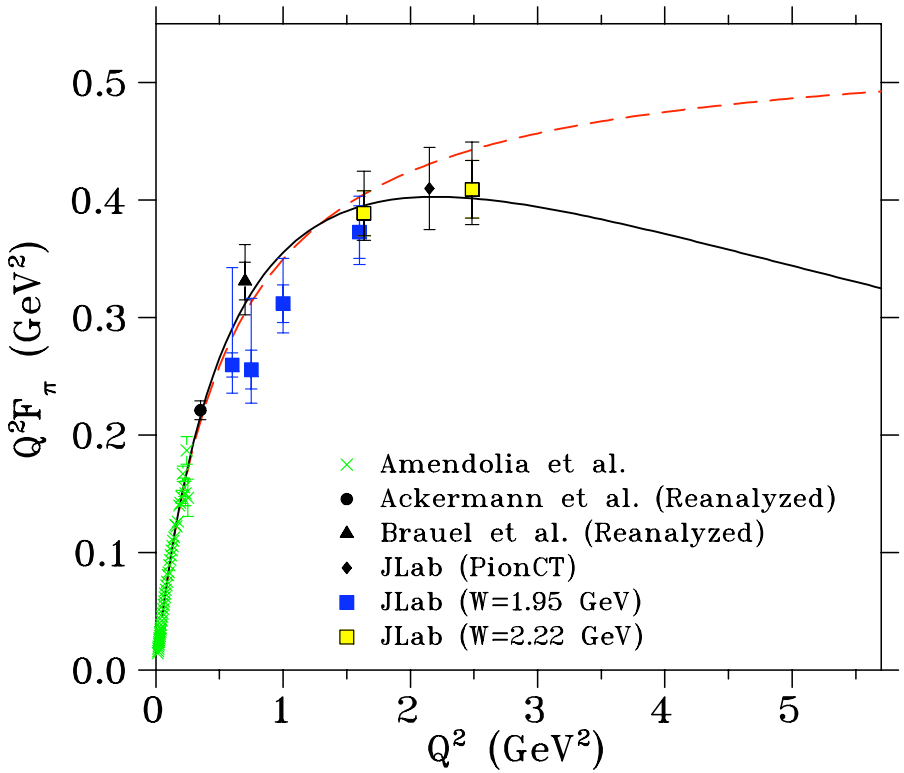
Pion Transverse Charge Density

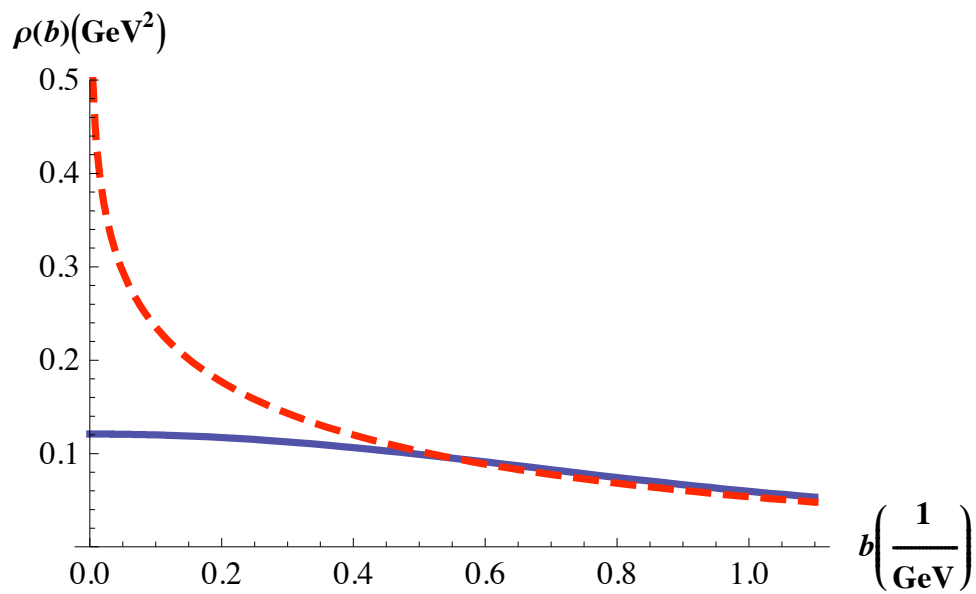
$$F_\pi(Q^2) = 1/(1 + R^2 Q^2/6),$$

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

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

Dashed- monopole fit, solid rel. cqm Huang





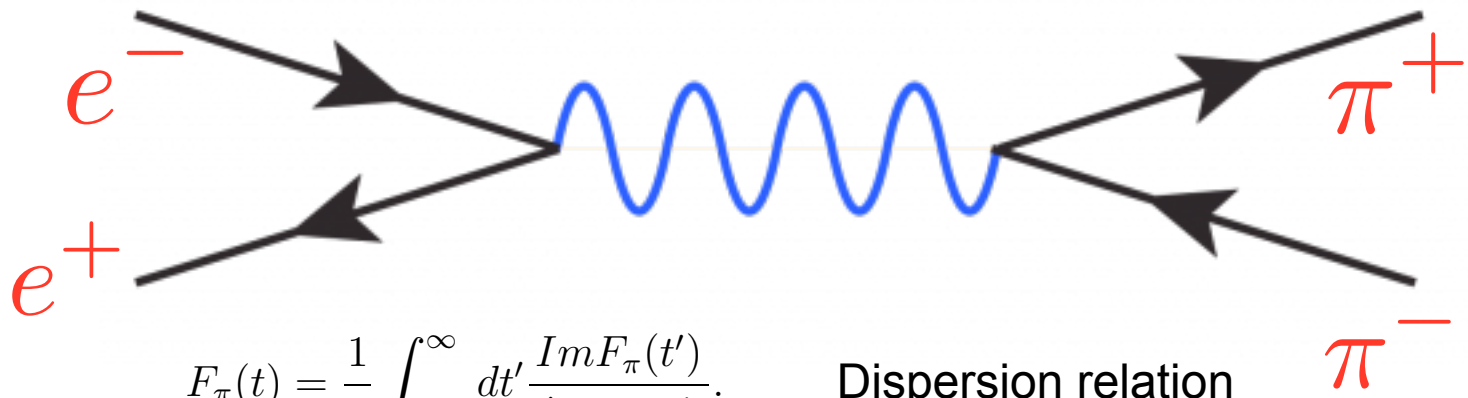
G A Miller Phys. Rev.C79 (2009)055204

PHYSICAL REVIEW D **83,** 013006 (2011)

Pion transverse charge density from timelike form factor data

G. A. Miller,[1] M. Strikman,[2] and C. Weiss[3]

MSW



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

Dispersion relation

Use this expression in equation for transverse density.

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

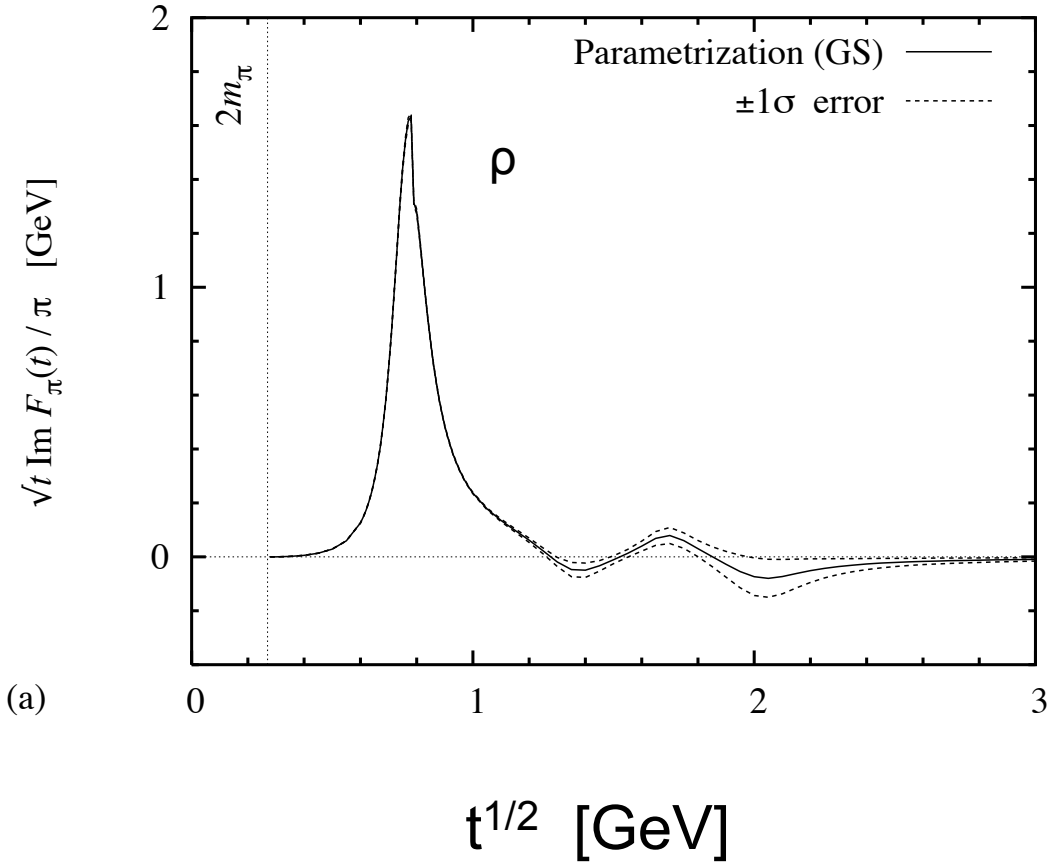
Low t' dominates except for very small values of b

Model needed: C. Bruch et al E. J Phys.C39, 41: Vector Meson Dominance Gouranis Sakurai

Modeling the pion and kaon form factors in the timelike region

C. Bruch[1], A. Khodjamirian[2,a], J.H. Kühn[1]

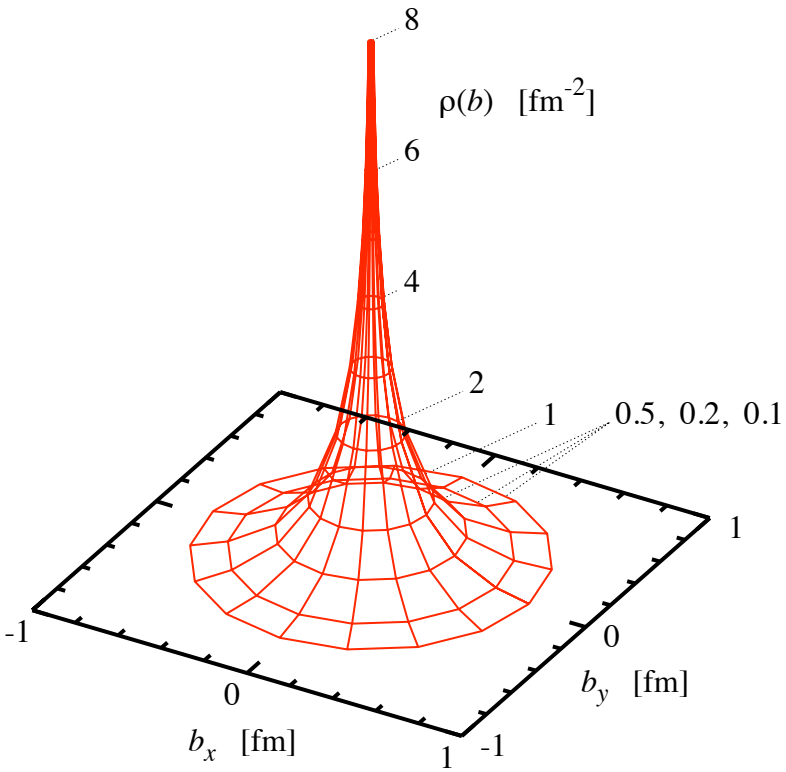
Eur. Phys. J. C 39, 41–54 (2005)

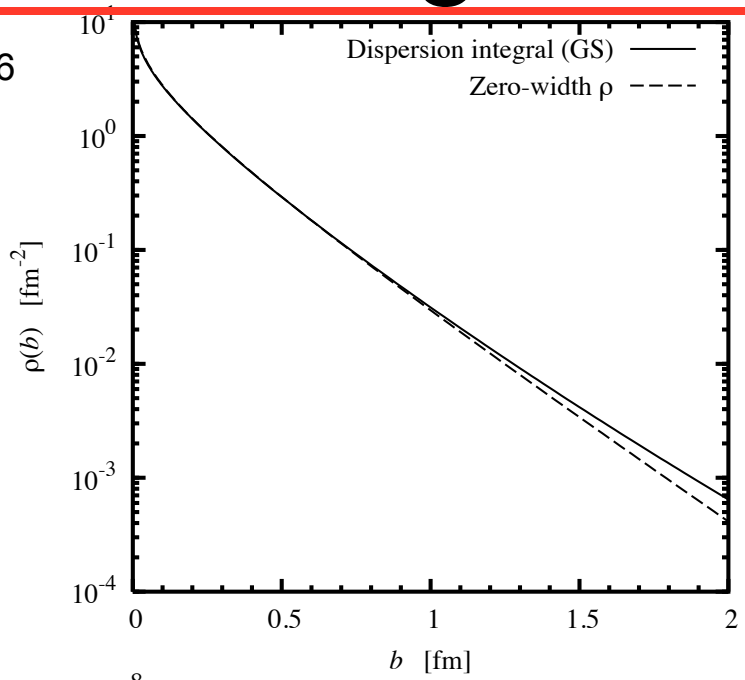


MSW PRD83,013006

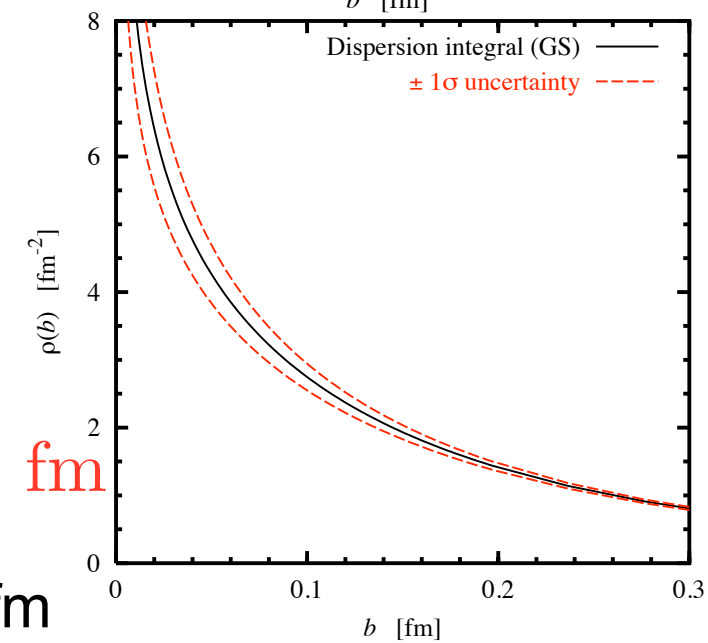
Pion Transverse Charge Density

MSW PRD83,013006





Singular at small b



$\rho_\pi(b)$ is known for $b > 0.1$ fm

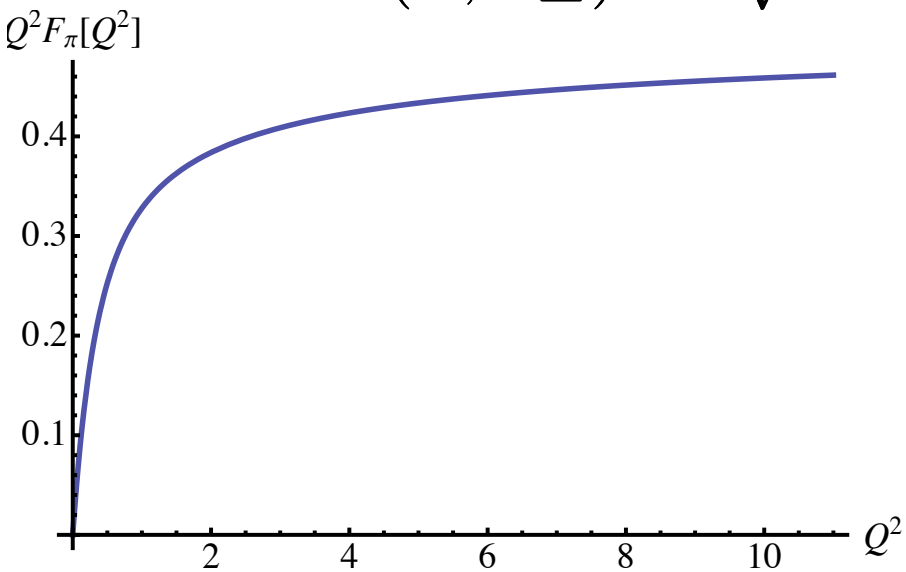
~20 % of probability for b<0.1 fm

Two ways to get small b: r=separation, b=r(1-x)

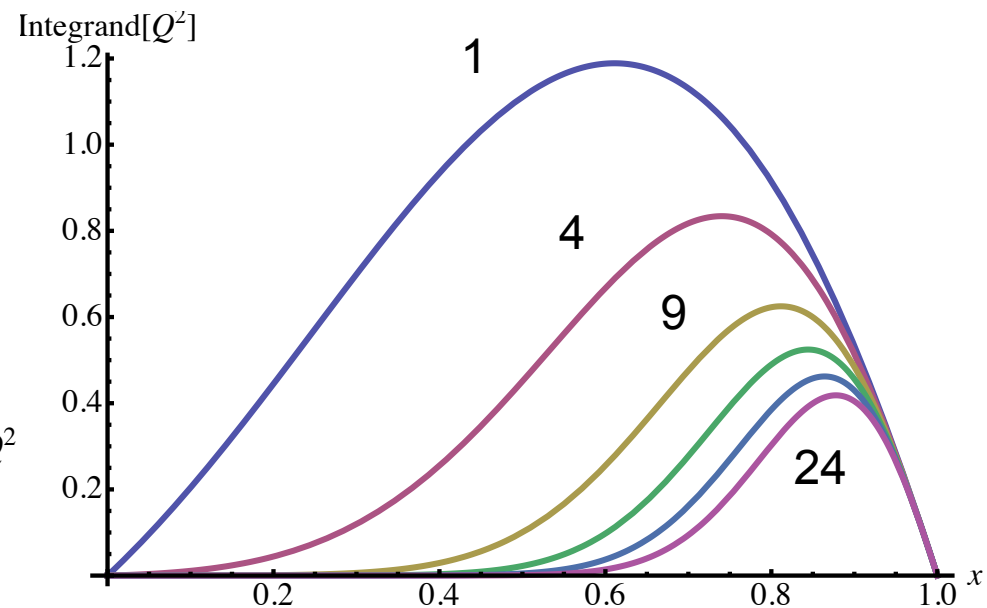
- Can have small r or large x
- If x is not near 1, small r and small b have same meaning so pion has PLC
- In general don't expect much prob for x near 1
- Suppose Feynman mechanism dominates, form factor arises from x near 1: how much of transverse charge density occurs at small r? Does pion have PLC or not? Can small b come from LARGE r?

Model with Feynman mechanism -updated Isgur Llwellyn Smith NPB317,526

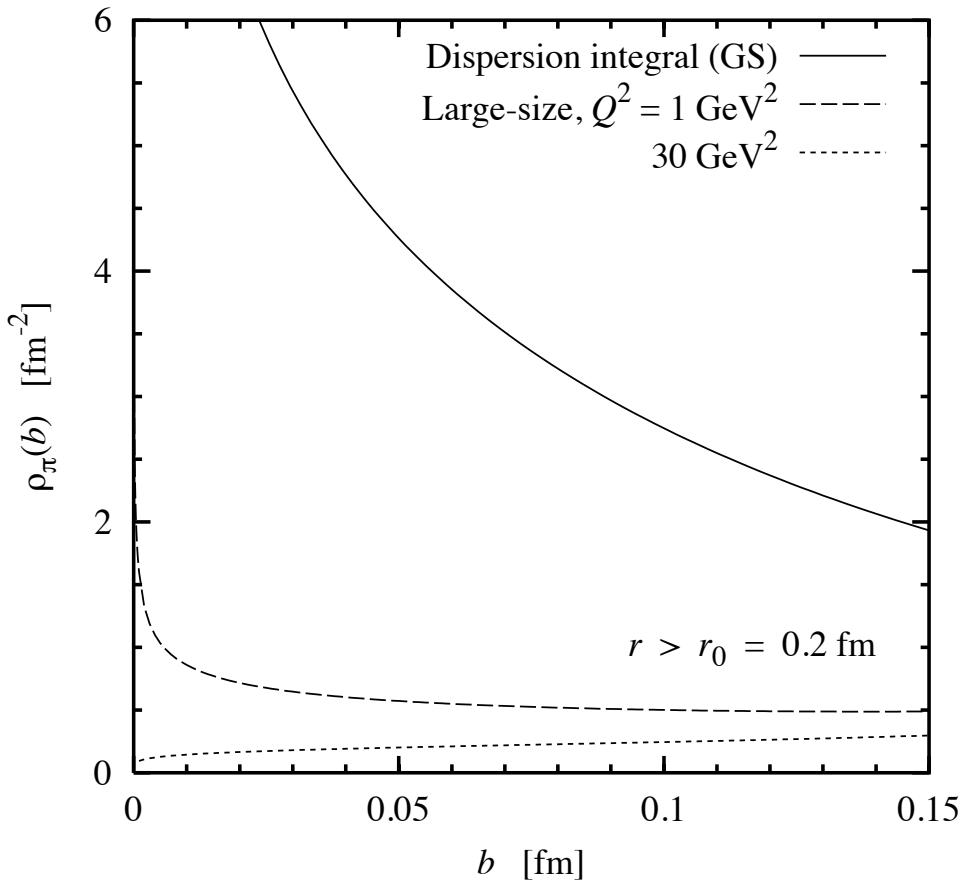
$$\Psi(x, k_\perp) = \sqrt{6x(1-x)}\, e^{-\frac{k_\perp^2}{2\beta^2}}\, (\pi\beta^2)^{-1/2}$$



β Fit to Jlab at 2.5 GeV^2



Feynman mechanism
x nears 1



Small b from large r? no

MSW PRD83,013006

Define conditional probability: contributions to ρ, small b, large r, $r > r_0$
Use $r = b/(1-x), x \geq 1 - b/r_0$

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

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