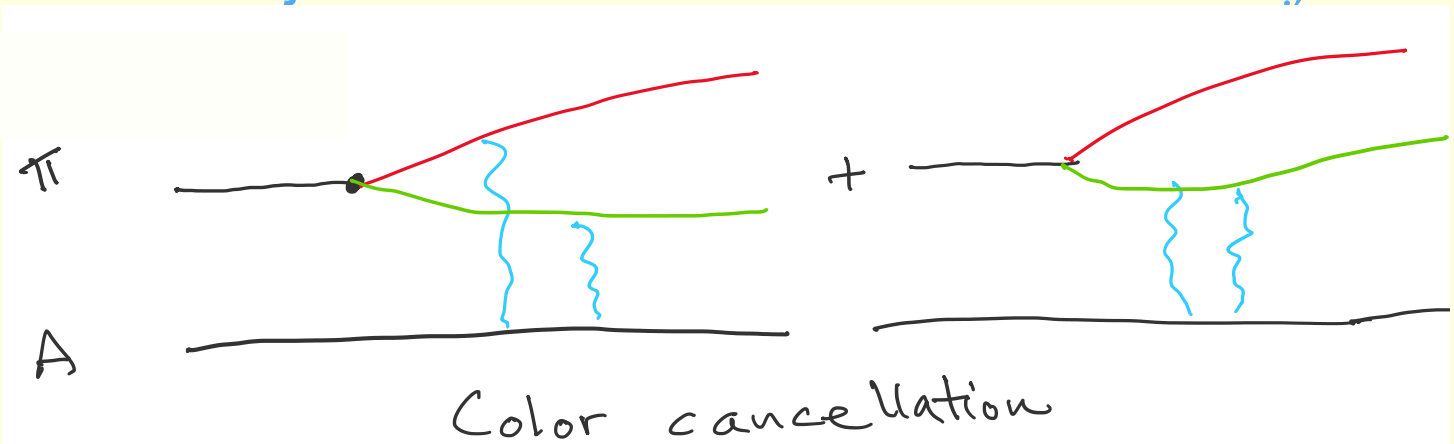
Color Transparency Past, Present and Future

G. A. Miller, UW, Seattle

Color transparency- reduced initial/final state interactions in coherent reactions

1. high-momentum transfer reactions make point-like color singlet states PLC

2. Small objects have small cross sections $Im f \propto b^2$



Diffractive Dissociation

3. PLC are not eigenstates-expand as they move Frankfurt& Strikman, Jennings & Miller

2,3 must be true, 1 is interesting ? -

Office of Science
U.S. Department of Energy

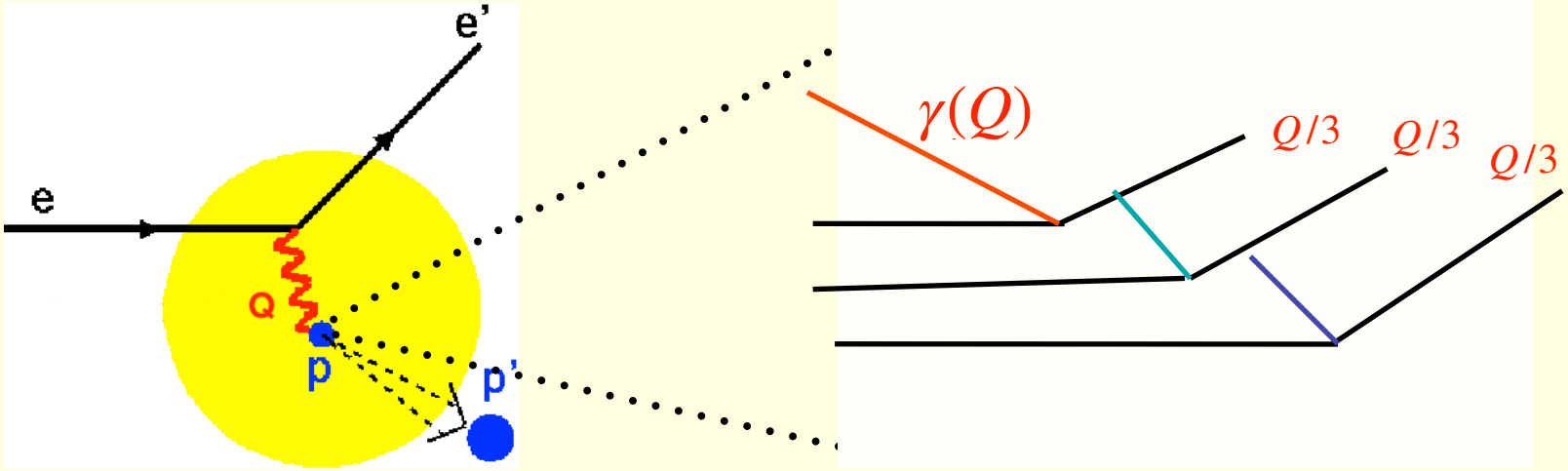
Color Transparency Idea

Why interesting?

- new dynamical phenomena- turn off strong interactions
- are PLCs made? -high Q^2-exclusives
- nuclear physics implications of PLC- nucleon modified- EMC effect

Why PLC at high momentum transfer?

Example: e-p scattering



Form factor enters

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

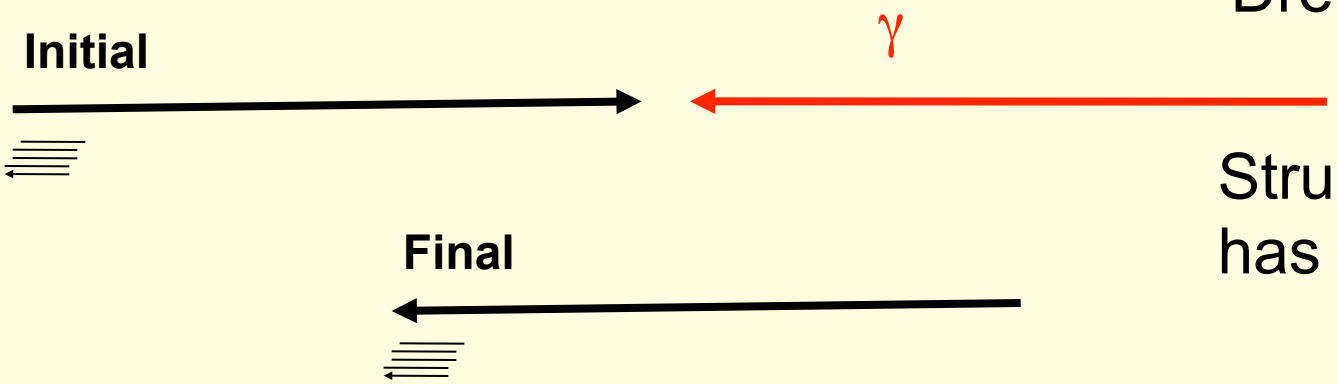
- At high enough Q an exclusive interaction occurs if the transverse size of the hadron is smaller than the equilibrium size.
- Perturbative reasoning-also non-perturbative Nucl.Phys. A555 (1993) 752-764

Why not PLC ?

e-p scattering **Feynman mechanism**

R. P. Feynman, *Photon-Hadron Interactions* (W. A. Benjamin, Inc.l, Reading, MA, 1972).

Drell & Yan



Transverse size not affected –no PLC

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

Making PLC is squeezing- and is the interesting part

Feynman:

remarked that "if a system is made of 3 particles, the large Q^2 behavior depends not on the singularity when just two come together, but rather when all three are on top of one another". Furthermore, "such pictures are too simple and inadequate".

First &Second Evidence?

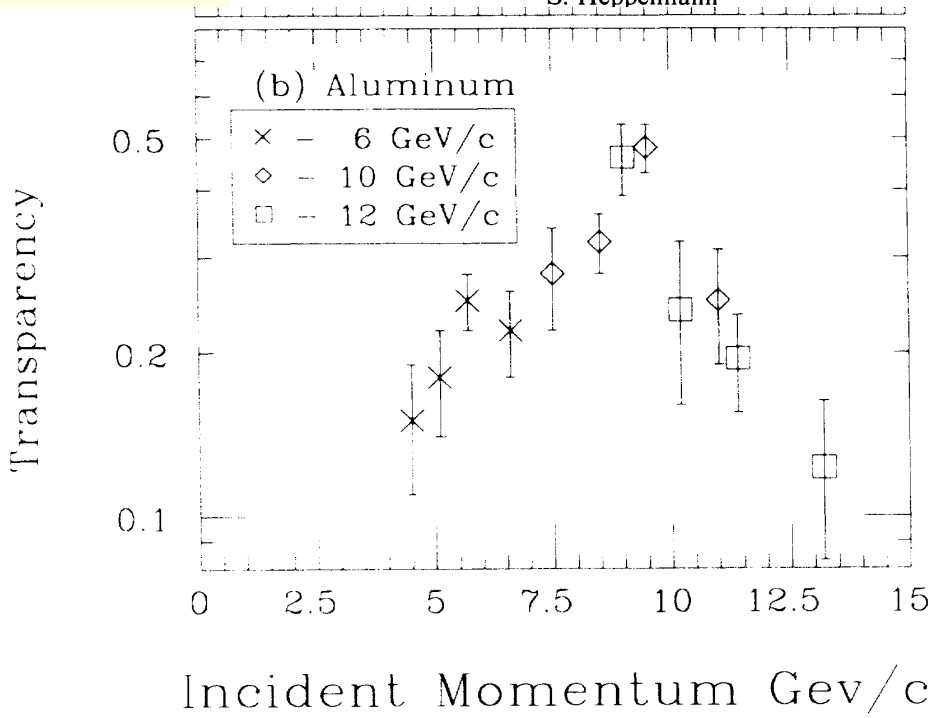
VOLUME 61, 1698 PHYSICAL REVIEW LETTERS

Nuclear Transparency to Large-Angle *pp* Elastic Scattering

A. S. Carroll, D. S. Barton, G. Bunce, S. Gushue, and Y. I. Makdisi
Brookhaven National Laboratory, Upton, New York 11973

S. Heppelmann

σ/σ_B



This rise and drop is not explained

Color transparency experiments

$T = \sigma/\sigma_B$

- (π, JJ)**Prediction Frankfurt et al. Phys.Lett. B304 (1993) 1. Experiment D Ashery et al PRL 86(2001) 4773** A-dependence
- $(e, e'\pi)$ **B. Clasie** *et al.* **PRL 99(2007)242502-Promising rise in** T
- $(e, e'\rho)$ **L. El Fassi** *al.* **PLB 712 (2012) 326- Promising rise in** T
- Many (e,e'p) experiments, no evidence for CT

  $\pi + A \rightarrow J + J + A$ is diffractive dissociation

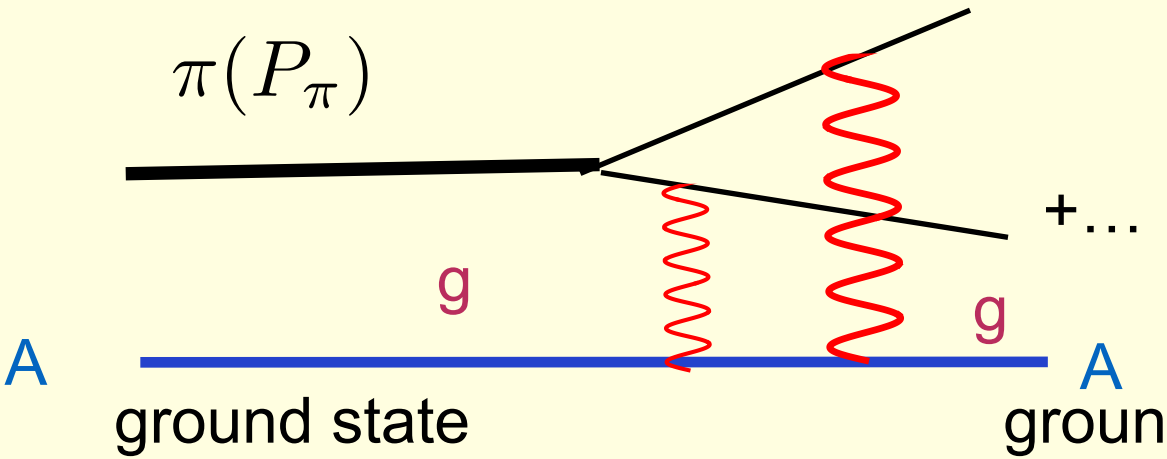
  π break up caused by 2 gluon exchange with target

  $(e, e'\pi), (e, e'p)$ reactions depend on form factor

  $(e, e'\rho)$ may not be two gluon driven at low energies

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

The one that worked



$p_\pi = 500\,\mathrm{GeV}$

- final state $q\bar{q}$ becomes 2 high rel. moment jets, select PLC component of pion
- $\pi \rightarrow q\bar{q}$ before hit target, no expansion
- one interaction
- Coherent process- enhanced!

FMS **Phys.Lett. B304 (1993) 1**

Phys. Rev D65,094015

$\mathscr{M}(\text{forward}) \propto A,\ \sigma_A \propto A^2 * A^{-2/3} = A^{4/3} + \text{positive corrections}$

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

♡ Coherent peak is well resolved:

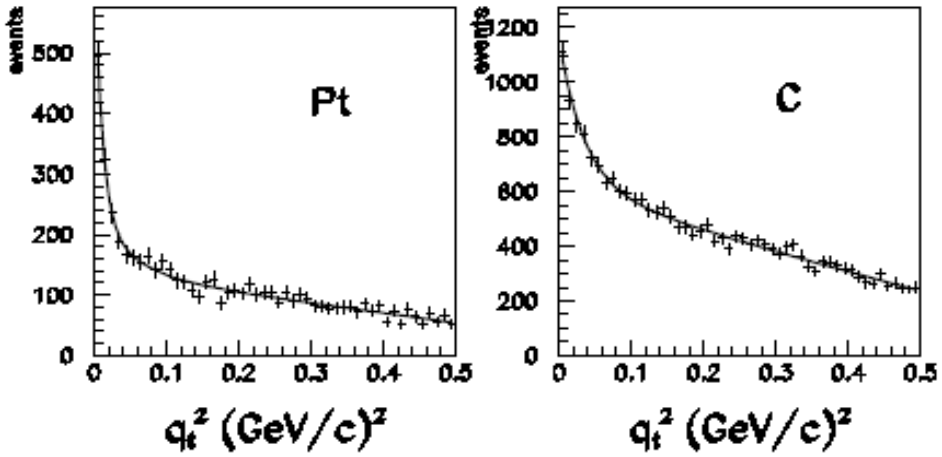


TABLE I. The exponent in $\sigma \propto A^{\alpha}$, experimental results for coherent dissociation and the color-transparency predictions.

k_t bin GeV/c	α	$\Delta\alpha_{\rm stat}$	$\Delta\alpha_{\rm sys}$	$\Delta\alpha$	α (CT)
1.25–1.5	1.64	±0.05	+0.04 −0.11	+0.06 −0.12	1.25
1.5–2.0	1.52	±0.09	±0.08	±0.12	1.45
2.0–2.5	1.55	±0.11	±0.12	±0.16	1.60

PRL 86,4773

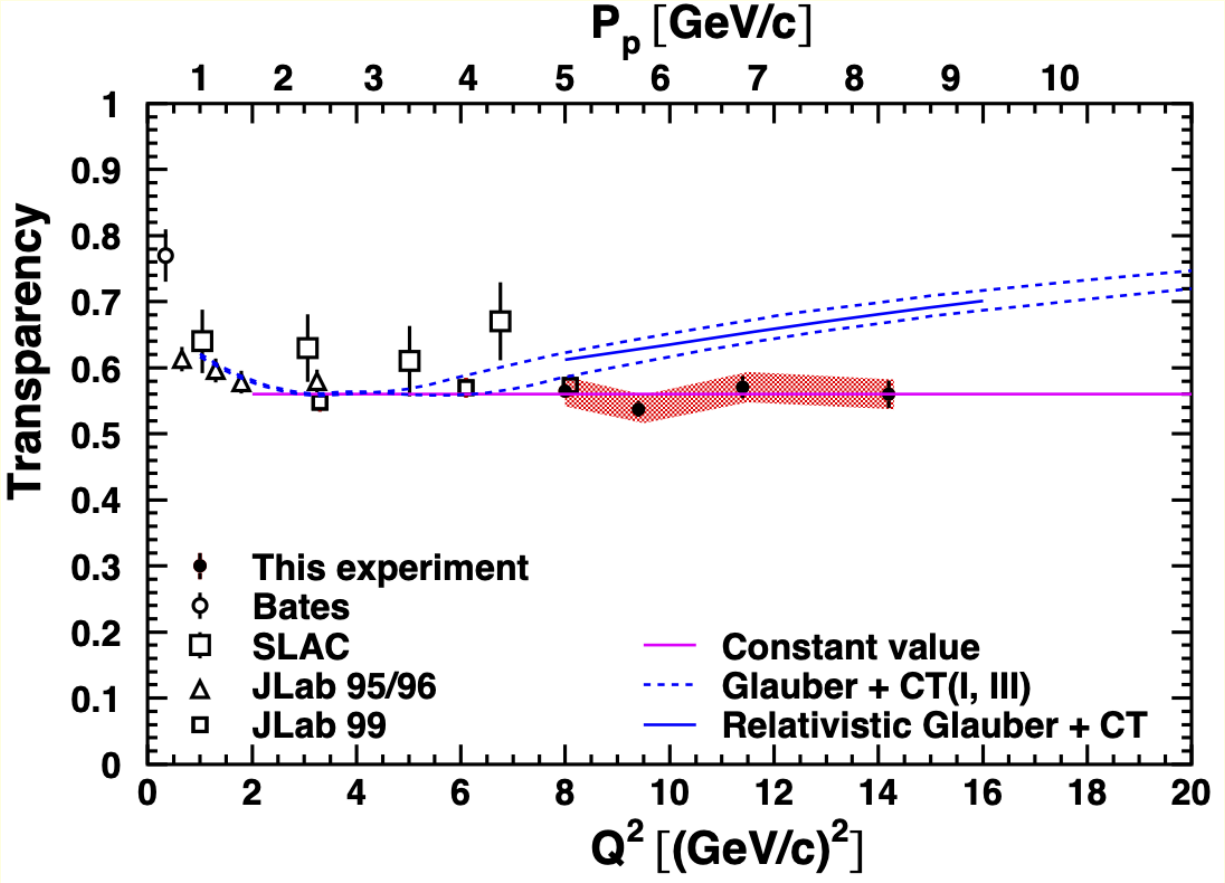
♡♡ Observed A-dependence $A^{1.61\pm0.08}$ $[C \to Pt]$

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!!

Ruling out color transparency in quasi-elastic ^{12}C(e,e′p) up to Q^2 of 14.2 (GeV/c)^2

Phys. Rev. Lett. 126, 082301



JLab: expansion is the problem

Goal: evaluate effects of expansion with new approach
Olivia Caplow-Munro, G A Miller 2104.11168

Light front (LF) wave functions of Holographic QCD:

- Stanley J. Brodsky, Guy F. de Teramond, Hans Gunter Dosch, and Joshua Erlich, "Light-Front Holographic QCD and Emerging Confinement," Phys. Rept. 584, 1–105 (2015), arXiv:1407.8131 [hep-ph].

First semiclassical approximation: quantum loops & $m_q = 0$
relativistic bound-state equation reduced to effective LF Schroedinger eq.

Invariant mass of free constituents is the dynamical variable $\zeta = \sqrt{b^2 x(1-x)}$,
measures parton separation at equal light-front time (deTeramond:2008ht).

QCD multi-parton problem reduced (first semi-classical approximation) to effective 1-dimensional quantum mechanics

complexities of strong interaction in effective potential U

Formalism quark-diquark model

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta, J) \right) \phi(\zeta) = M^2 \phi(\zeta)$$

$$\zeta^2 = b^2 x(1-x), \ \phi \text{ prob . amp .}$$

L, J orbital total ang mom .

Depends on Hadron

$$U(\zeta, J) = \kappa^4 \zeta^2 + 2\kappa^2 (J-1)$$

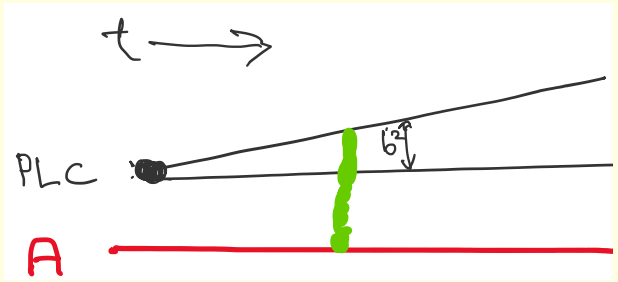
- Excellent baryon & meson spectroscopy, form factors Feynman mechanism PR102.081601,PRD.91.045040,PRD.91.085016
- Gives wave functions at fixed value of x
- OK because interactions with medium $\propto b^2$

Time dependence

$$2i\frac{\partial}{\partial\tau}\Psi = \frac{1}{P^+}\left(-\frac{1}{x(1-x)}\nabla_b^2 + U(b^2(x(1-x),J)\right)\Psi,$$

$$\tau \equiv x^+, \Psi = \text{PLC wave packet}$$

- Procedure, $H \rightarrow L$, Legendre trans. (Momentum to velocity)
- Use path integral formalism to get τ development operator $K(t)$
- $$b^2(t) \equiv \frac{\langle \Psi_{00} | b^2 K(t) | \text{PLC} \rangle}{\langle \Psi_{00} | \text{PLC} \rangle}$$



- Effective size of PLC moving thru nucleus
- First-order in multiple scattering $b(0) = 0$, here

Rate of Expansion Depends on Hadron

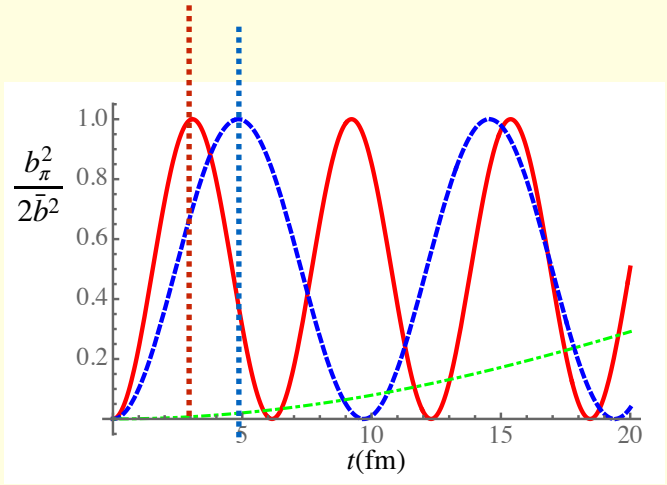
$$\frac{b_\pi^2}{2\bar{b}^2} = \sin^2\left(\frac{2\kappa^2}{P^+}t\right)$$

$$\frac{b_\rho^2}{2\bar{b}^2} = \sin\left(\frac{2\kappa^2}{P^+}t\right)\sin\left(\frac{4\kappa^2}{P^+}t\right)$$

$$\frac{b_N^2}{2\bar{b}^2} = \sin\left(\frac{2\kappa^2}{P^+}t\right)\sin\left(\frac{6\kappa^2}{P^+}t\right).$$

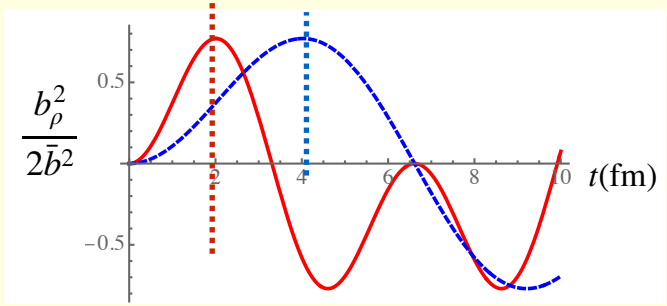
Meson results- expansion time , t_E, : vertical lines

Pion: t_E between 2 and 5 fm in exp. CT seen more Likely



Expansion does not occur for Flab Experiment

FIG. 2. $\frac{b_\pi^2}{2\bar{b}^2}$. Solid (red) $P_\pi^+ = 5.5$ GeV, Dashed (blue) $P_\pi^+ = 8.8$ GeV, Dot-dashed (green) $P_\pi^+ = 100$ GeV. t is in units of fm



Rho: t_E between 2 fm for exp. CT less likely Higher energy would see CT

FIG. 3. $\frac{b_\rho^2}{2\bar{b}^2}$. Solid (red) $P_\rho^+ = 6$ GeV, Dashed (blue) $P_\rho^+ = 12$ GeV. t is in units of fm

Proton results & Conclusion

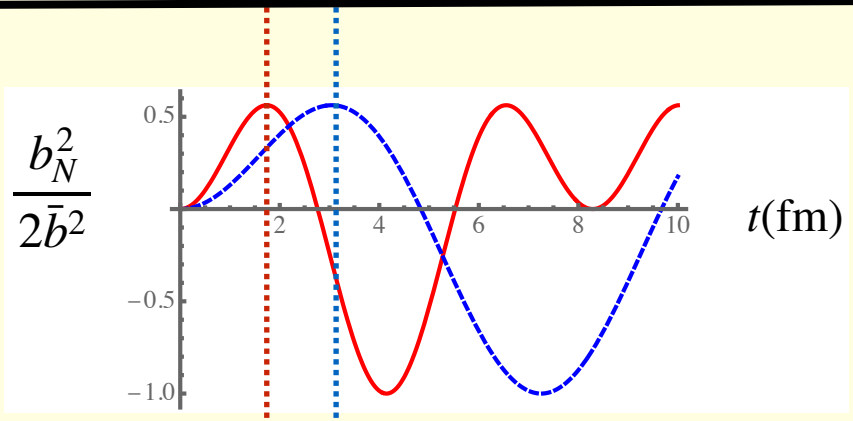


FIG. 4. $\frac{b_N^2}{2\bar{b}^2}$ Solid (red) $P_N^+ = 8$ GeV, Dashed (blue) $P_N+ = 14$ GeV. t is in units of fm.

t_E ranges between 2 and 3fm . For ^{12}C CT should have seen as rise in transparency ratio

Expansion is not excuse for lack of CT

Conclude PLC is not formed

Feynman mechanism is responsible for proton em form factor at high Q^2

Diffractive dissociation to jets seems more promising only one Bound-state wave function involved. Two gluon exchange