Neutron negative charge density:Exclusive-Inclusive Connection

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Outline-

1. How not to and how to analyze electromagnetic form factors- transverse density

2. Model independent proton, neutron transverse charge density

3. Interpret neutron charge density -relate to high x pdfs

Transverse Charge Densities.
Gerald A. Miller, arXiv:1002.0355 [nucl-th] ARNPS

Interpretation of Sachs - $G_E(Q^2)$ is Fourier transform of charge density

$$R^2 = -6\frac{dG_E(Q^2)}{dQ^2}|_{Q^2=0}$$

Correct non-relativistic:

wave function invariant under Galilean transformation, BUT IT IS WRONG

Relativistic : wave function is frame dependent, initial and final states differ

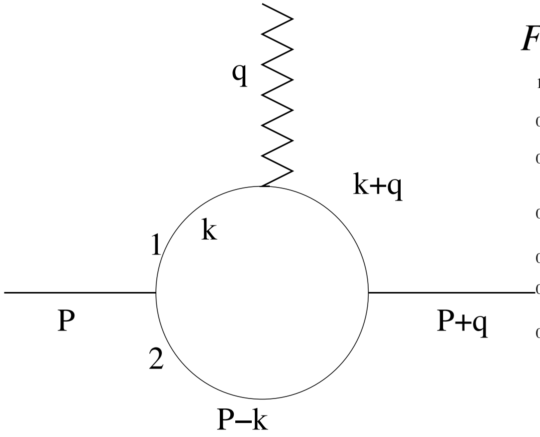
interpretation of Sachs FF is wrong

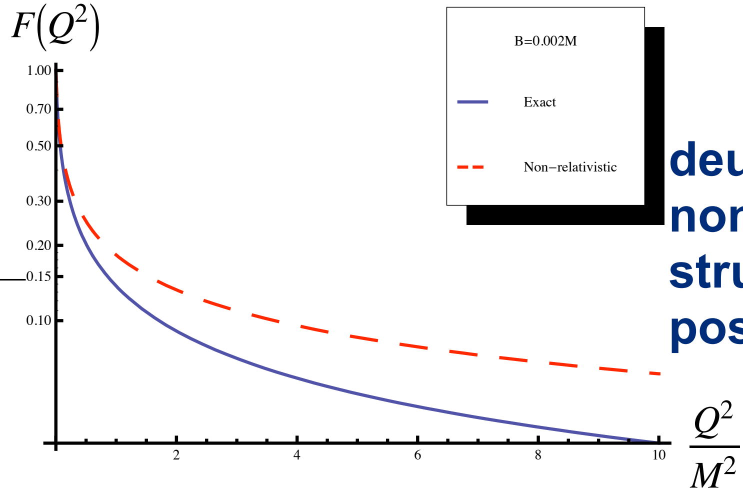
Final wave function is boosted from initial

Need relativistic treatment

Toy model GAM, Phys.Rev.C80:045210,2009.

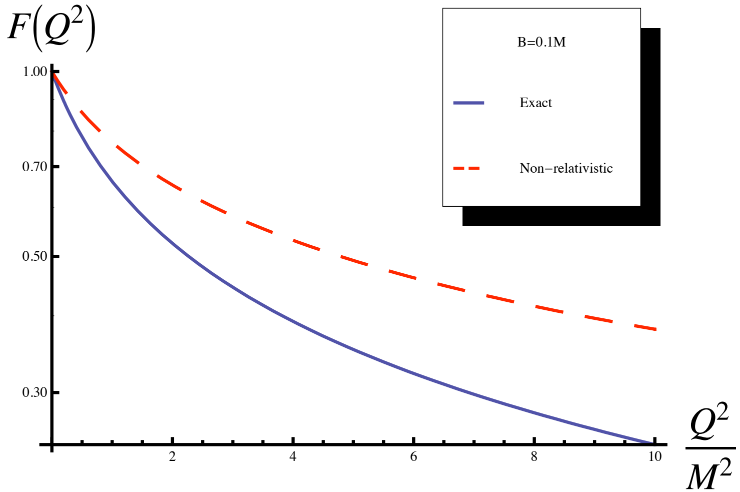
Scalar meson M, made of two scalar mesons, m
IF (M-2m)/M, small non-relativistic works





deuteron kinematics are non-relativistic: extract neutron structure function should be possible

(M-2m)/M=0.002



Relativity needed

(M-2m)/M=0.1

Exact *vs* non-relativistic Form factors for the case $m_1 = m_2 = m$.

Light front, Infinite momentum frame

$$\text{"}Time\text{"},\ x^+ = x^0 + x^3, \quad \text{"}Evolve\text{"},\ p^- = p^0 - p^3$$

$$\text{"}Space\text{"},\ x^- = x^0 - x^3, \quad \text{"}Momentum\text{"},\ p^+ (\text{Bjorken})$$

$$Transverse\ position,\ momentum \quad \mathbf{b}, \mathbf{p}$$

These variables are used in GPDs, TMDs, standard variables

transverse boosts in kinematic subgroup

$$\mathbf{k} \rightarrow \mathbf{k} - k^+ \mathbf{v}$$

$$\text{space} - \text{like } q^\mu, q^+ = 0,$$

$$\text{momentum transfer in transverse direction}$$

then density is 2 Dimensional Fourier Transform

Model independent transverse charge density

$$J^+(x^-,\mathbf{b}) = \sum_q e_q q_+^\dagger(x^-,b) q_+(x^-,b)$$ Charge Density

$$\rho_\infty(x^-,\mathbf{b}) = \langle p^+, \mathbf{R}=\mathbf{0},\lambda| \sum_q e_q q_+^\dagger(x^-,b) q_+(x^-,b) |p^+,\mathbf{R}=\mathbf{0},\lambda\rangle$$

$$F_1 = \langle p^+, \mathbf{p}', \lambda | J^+(0) | p^+, \mathbf{p}, \lambda\rangle$$

$$\rho(b) \equiv \int dx^- \rho_\infty(x^-,\mathbf{b}) = \int \frac{QdQ}{2\pi} F_1(Q^2) J_0(Qb)$$

Soper '77

Density is $u - \bar{u},\ d - \bar{d}$

Impact parameter dependent GPD Burkardt

Probability that quark at b from CTM has long momentum fraction x

0 skewness, $\xi = 0$

$$\rho^q(b,x) = \int \frac{d^2q}{(2\pi)^2} e^{-i\mathbf{q}\cdot\mathbf{b}} H_q(x, t = \mathbf{q}^2)$$

$$\rho(b) = \sum_q e_q \int dx \rho^q(b,x)$$

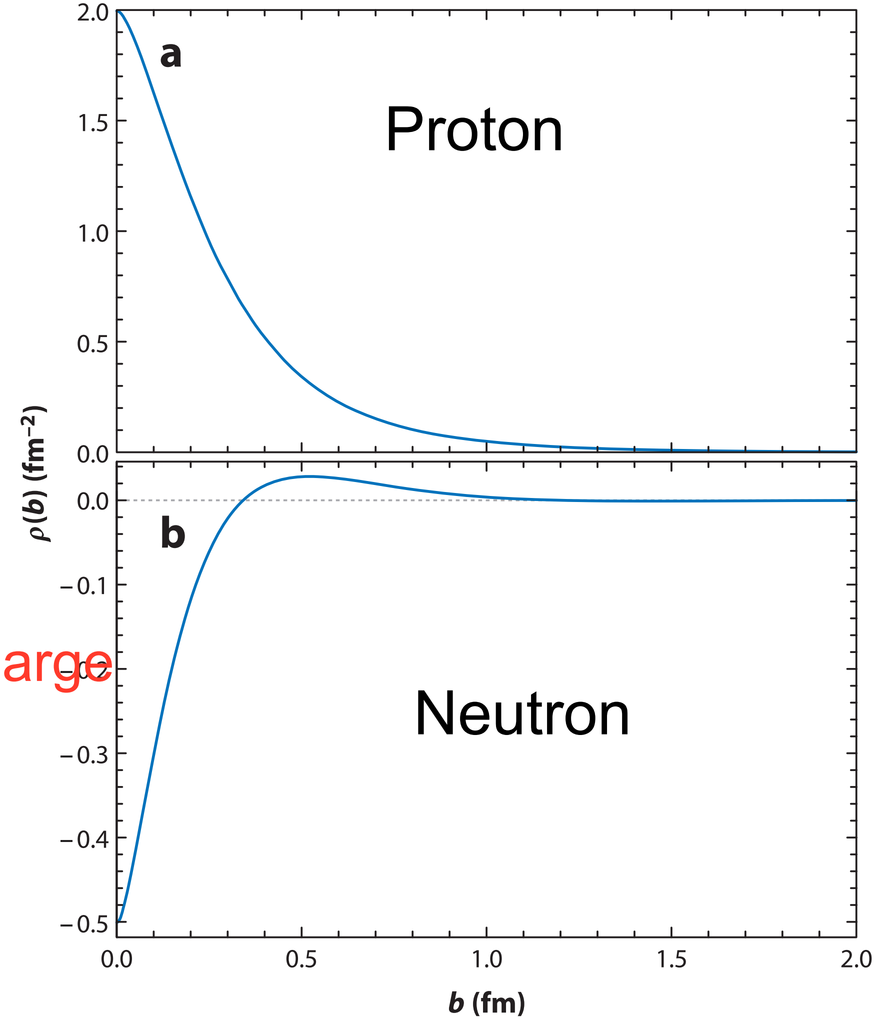
sum rule: integral of H_q is F

$$\mathbf{R} = \mathbf{0} = \sum_i^N x_i \mathbf{b}_i$$

Quark of x=1, must have b=0

Transverse density is integral over longitudinal position or momenta
example of Parseval's theorem

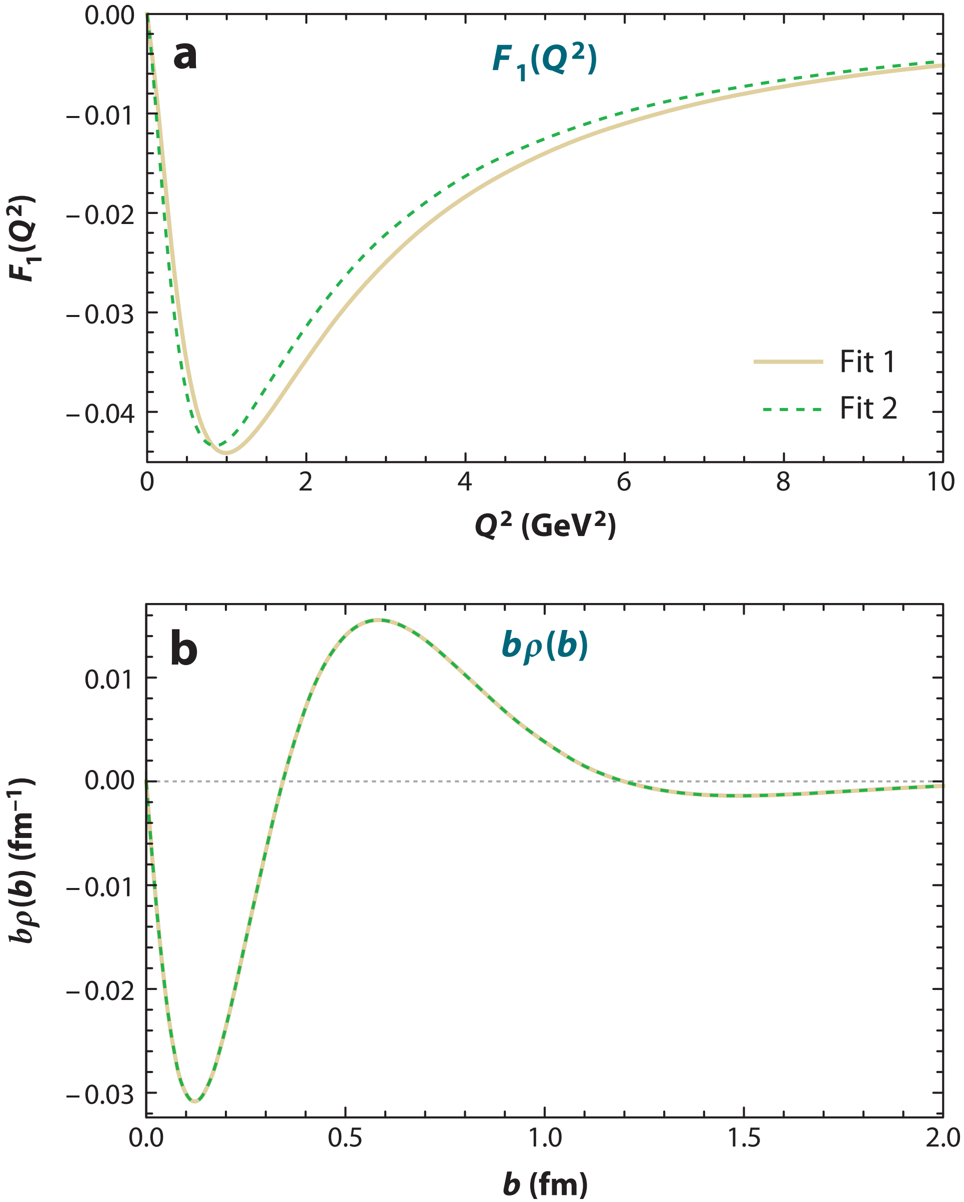
Transverse charge densities from parameterizations (Alberico)



Negative central charge density

Negative central density - GAM PRL '07

Neutron

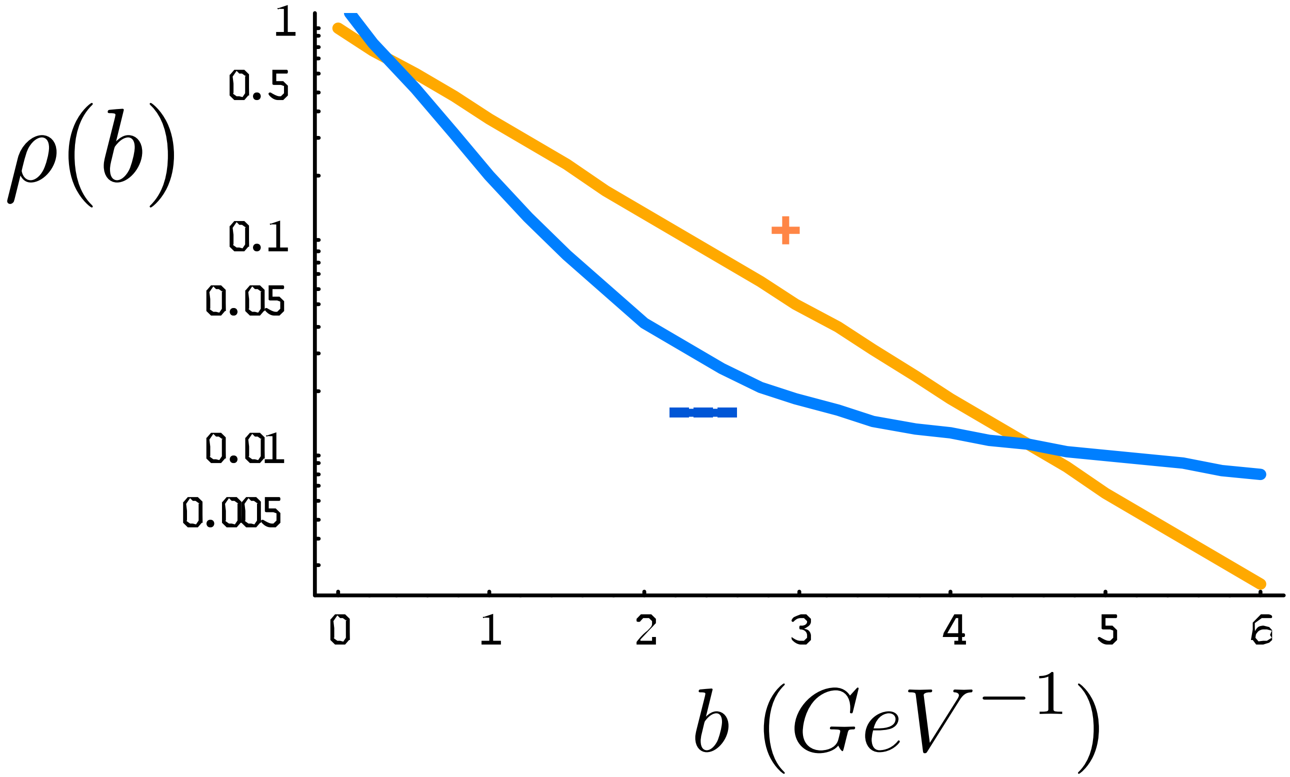


F_1 is negative, so is central density

Negative at large b, pion cloud? see Strikman Weiss '10

arXiv:1004.3535

Neutron charge density: why?



Neutron interpretation

- Impact parameter gpd Burkardt $\rho(x, b)$
- Drell-Yan-West relation between high x DIS and high Q^2 elastic scattering
- High x related to low b, not uncertainty principle

$$\lim_{x\to 1} \nu W_2(x) = (1-x)^{2n-1} \leftrightarrow \lim_{Q^2\to\infty} F_1(Q^2) \sim \frac{1}{Q^{2n}}, n=2$$

- Various (reasonable) assumptions needed: power-law wave functions. Is this relationship valid?

$$\pi \text{ DYW} : F(Q^2) \sim \frac{1}{Q^2} \to \nu W_2 = (1-x)$$

$$\text{But Reimer data } (1-x)^2$$

?????

Structure functions

- d quarks dominate DIS from neutron at high x
- d quarks dominate at neutron center, or π^{-}

$$\text{Density is } u - \bar{u},\ d - \bar{d}$$

$$\pi^{-} \text{ is } \bar{u}d$$

$$\text{decreases } u \text{ contribution}$$

$$\text{enhances } d \text{ contribution}$$

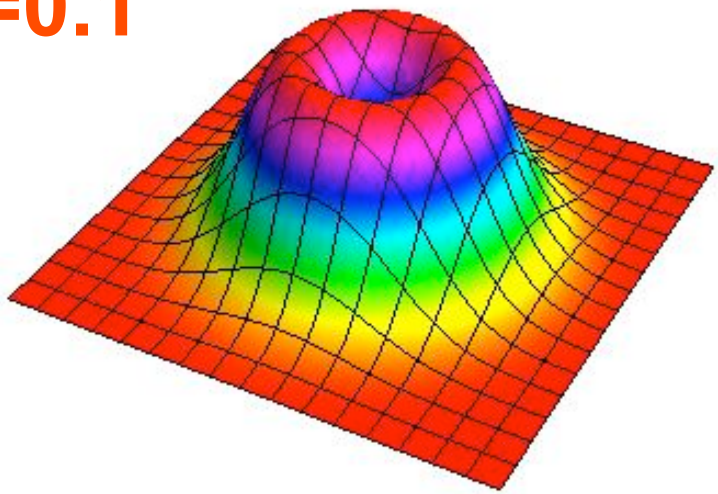
Neutron interpretation ρ(x,b)

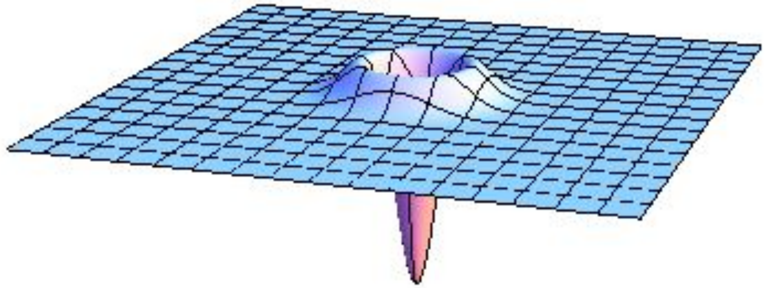
GAM, J. Arrington, PRC78,032201R '08

Guidal et al 05, Diehl et al 05, Ahmad07, Tiburzi04.

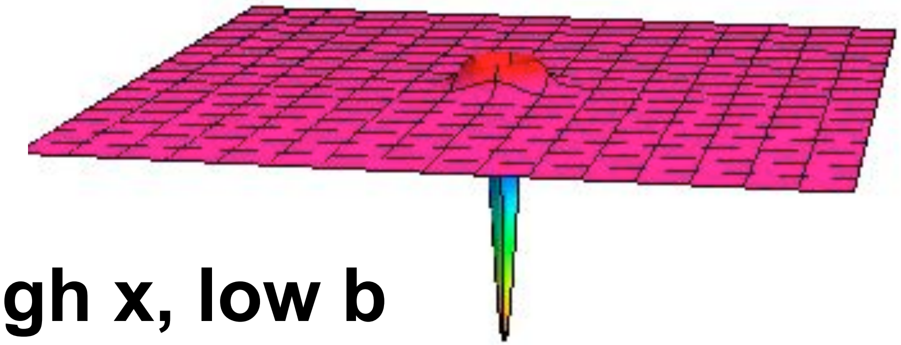
x=0.3

x=0.1



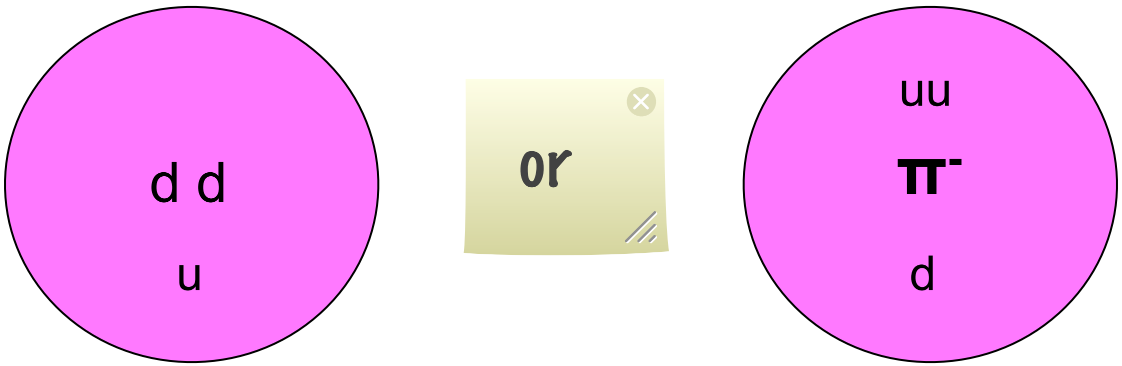


x=0.5

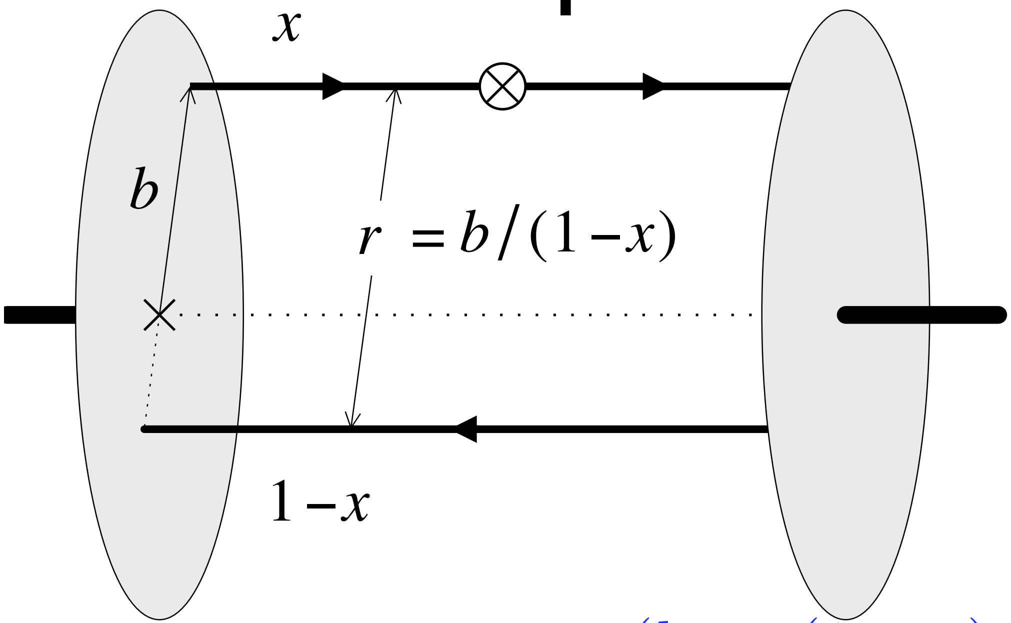


d or π^- dominates at high x, low b

Neutron interpretation



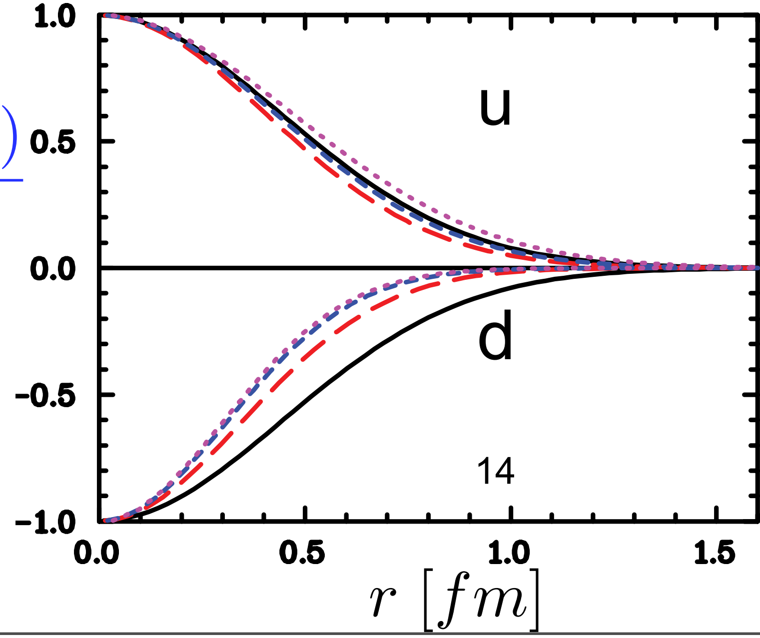
Understand b: quark and spectator system



Several values of x, little variation

$$\frac{\rho(b = r(1-x), x)}{\rho(0, x)}$$

Model dependent

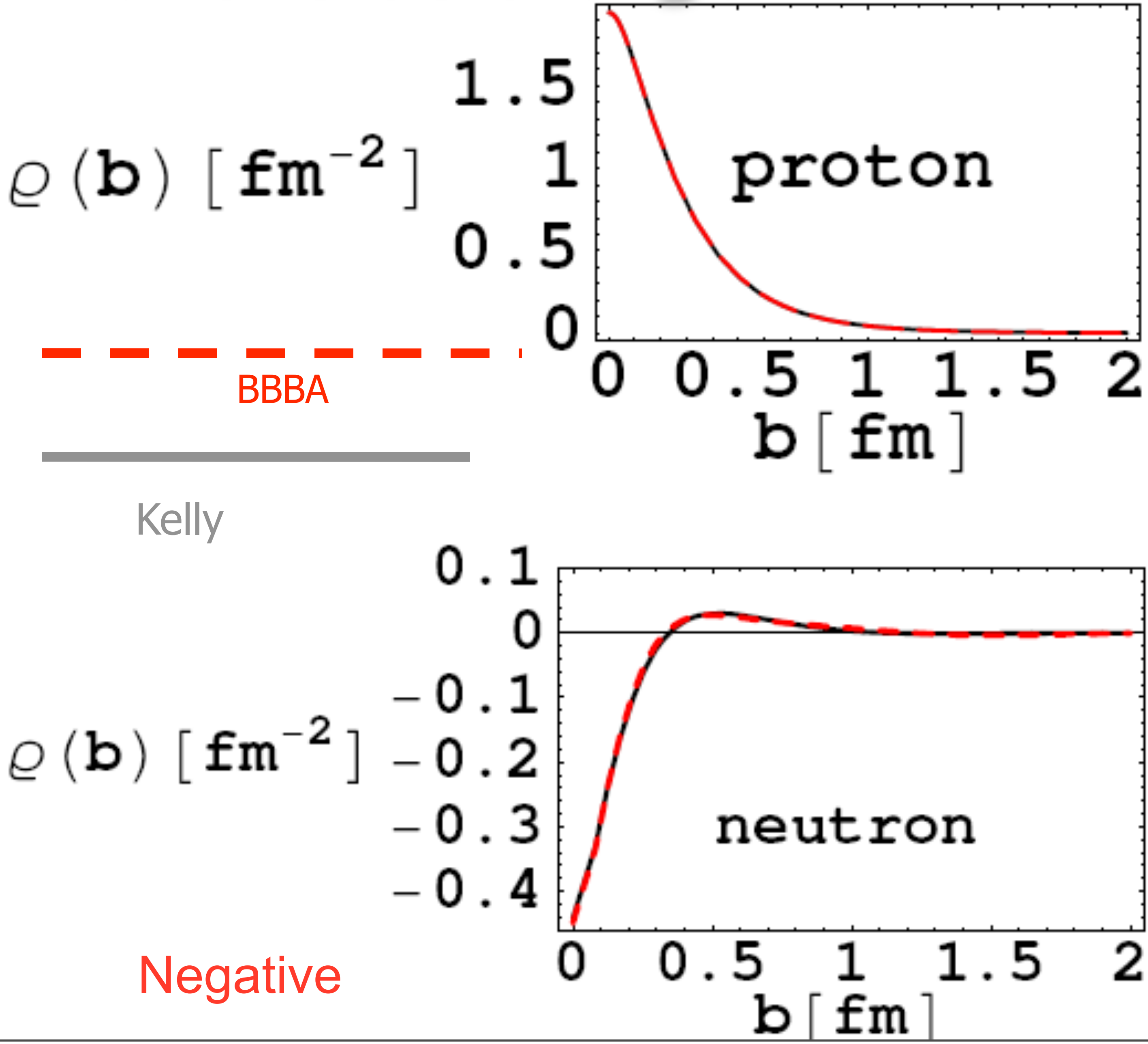


Summary

- Much data exist, Jlab12 will improve data set
- Charge density is not a 3 dimensional Fourier transform of G_E
- Interpret form factor as determining transverse charge density
- Neutron: Negative central density
- Full understanding needs $\rho(b, x)$
- Center of neutron: d or π
- Is Drell-Yan, West relation valid?

Spares follow

Transverse charge densities



Relation or not between GPD and TMD

$$\text{GPD}:$$

$$\langle P', S'| \int \frac{dx^-}{4\pi} \bar{q}(-\frac{x^-}{2}, \mathbf{0})\gamma^+ q(\frac{x^-}{2}, \mathbf{0}) e^{ix\bar{p}^+ x^-} |P, S\rangle_{\;x^+=0}$$

$$= \frac{1}{2\bar{p}^+} \bar{u}(P', S') \left(\gamma^+ H_q(\xi, t) + i \frac{\sigma^{+\nu}\Delta_\nu}{2M} E_q(x, \xi, t) \right) u(P, S)$$

$$\text{TMD}:$$

$$\Phi_q^\Gamma(x = \frac{k^+}{P^+}, \mathbf{k}) = \langle P, S| \int \frac{d\zeta^- d^2\zeta}{2(2\pi)^3} e^{ik\cdot\zeta} \bar{q}(0)\Gamma q(\zeta)|P, S\rangle_{\zeta^+=0}$$

GPD: nucleons have different momenta, but FT local in coordinate space if integrate over x

TMD: nucleons have same momenta, operator is local in momentum space

Both can be obtained Wigner distribution operator

$$W_q^\Gamma(\zeta^-, \boldsymbol{\zeta}, k^+, \mathbf{k})$$
$$= \frac{1}{4\pi}\int d\eta^- d^2\eta e^{ik\cdot\eta}\bar{q}(\zeta^- - \frac{\eta^-}{2}, \boldsymbol{\zeta} - \frac{\boldsymbol{\eta}}{2})\Gamma q(\zeta^- + \frac{\eta^-}{2}, \boldsymbol{\zeta} + \frac{\boldsymbol{\eta}}{2})$$

$$H_q(x,\xi,t) = \langle P', S'| \int \frac{d^2\mathbf{k}}{(2\pi)^2} W_q^{\gamma^+}(\zeta^- = 0, \zeta = 0, k^+, \mathbf{k})|P, S\rangle$$

$$\Phi_q^\Gamma(x,\mathbf{k}) = \langle P, S| \int \frac{d\zeta^-}{(2\pi)^2} W_q^\Gamma(\zeta^-, \zeta, k^+, \mathbf{k})|P, S\rangle$$