Charge Density of the Neutron

Gerald A. Miller
University of Washington

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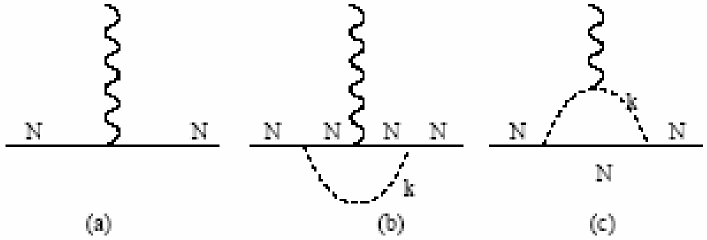
What do form factors really measure?

What is charge density at the center of the neutron?

- Neutron has no charge, but charge density need not vanish
- Is central density positive or negative?

Neutron: Need π cloud effect at low Q^2

Cloudy Bag Model 1980 **TTM**



Relativistic treatment needed Feynman graphs,

Light front cloudy bag model LFCBM 2002

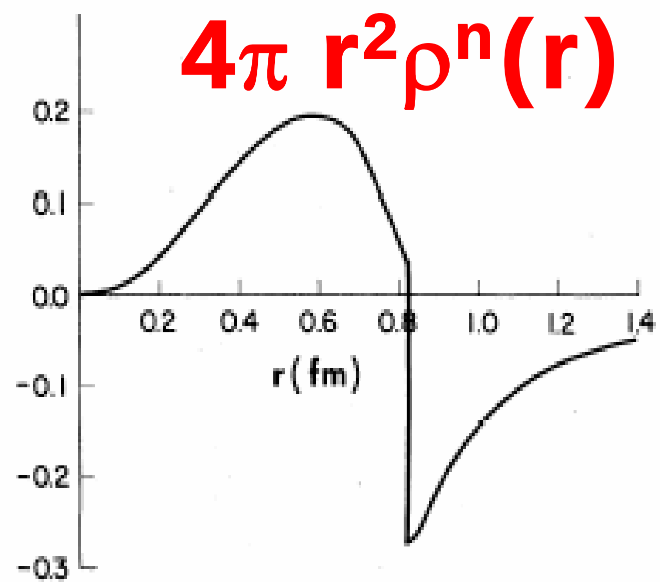


FIG. 11. Neutron charge density.

One gluon exchange also gives positive central charge density

Enough models- Today

model **ind**ependent information

Outline

- Electromagnetic form factors
- Light cone coordinates, kinematic subgroup
- GPDs + Bit of math →
- Two dimensional Fourier transf. of F_1 gives $\rho(b)$, Soper '77
- Data analysis, Interpretation

Definitions

$$\langle p', \lambda' | J^\mu(0) | p, \lambda \rangle = \bar{u}(p', \lambda') \left(\gamma^\mu F_1(Q^2) + i \frac{\sigma^{\mu\alpha}}{2M} q_\alpha F_2(Q^2) \right) u(p, \lambda)$$

$$G_E(Q^2) \equiv F_1(Q^2) - \frac{Q^2}{4M^2} F_2(Q^2), \; G_M(Q^2) \equiv F_1(Q^2) + F_2(Q^2)$$

Old Interpretation- Breit frame $\vec{p}\,' = -\vec{p}$

G_E is helicity flip matrix element of J^0

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

Correct non-relativisticaly

Non-relativistic two particle :

$$\Psi(\mathbf{r}_1, \mathbf{r}_2, t) = e^{i\mathbf{P}\cdot\mathbf{R} - i(\frac{P^2}{2M} - \epsilon)t}\phi(\mathbf{r})$$

ϕ invariant under Galilean transformation

Relativity: $(\mathbf{r}_1, t_1), (\mathbf{r}_2, t_2)$ $t_1 \neq t_2$

$\bar{e}^{i\,H(t_1 - t_2)}$ Interactions!

ϕ is frame dependent, interpretation of Sachs wrong

Why relativity if $Q^2 \ll M^2$

QCD- photon hits $\approx$ massless quarks

No matter how small Q^2 is, there is a boost correction that is $\propto Q^2$

$$F_1 \sim Q^2 R_N^2(|\psi|^2 + C/(m_q R_N)^2)$$

Light cone coordinates

$$\text{“Time”}\ x^+ = (ct + z)/\sqrt{2} = (x^0 + x^3)/\sqrt{2}$$

$$\text{“Evolution”}\quad p^- = (p^0 - p^3)/\sqrt{2}$$

$$\text{“Space”}\ x^- = (ct - z)/\sqrt{2} = (x^0 - x^3)/\sqrt{2},\ \text{If}\ x^+ = 0,\ \ x^- = -\sqrt{2}z$$

$$\text{“Momentum”}\quad p^+ = (p^0 + p^3)/\sqrt{2}$$

$$\text{Transverse : “Position” b “Momentum” p}$$

Relativistic formalism- kinematic subgroup of Poincare

- Lorentz transformation –transverse velocity v

$$k^+ \longrightarrow k^+, \;\; \mathbf{k} \longrightarrow \mathbf{k} - k^+\mathbf{v}$$

k^- such that k^2 not changed

Just like non-relativistic

Generalized Parton Distribution

$$H_q(x,t) = \int \frac{dx^-}{4\pi} \langle p^+, \mathrm{p}', \lambda | \bar{q}(-\frac{x^-}{2}, 0)\gamma^+ q(\frac{x^-}{2}, 0) | p^+, \mathrm{p}, \lambda \rangle e^{ixp^+x^-}$$

$$H_q(x, \xi = 0, t) \equiv H_q(x,t)$$

$A^+=0$, $t=(p-p')^2 = -Q^2 =- (\mathbf{p}' - \mathbf{p})^2$

$$H_q(x,t) \equiv \int \frac{dx^-}{4\pi} \langle p^+, \mathrm{p}', \lambda | \bar{q}(-\frac{x^-}{2}, 0) \gamma^+ q(\frac{x^-}{2}, 0) | p^+, \mathrm{p}, \lambda \rangle e^{ixp^+x^-}$$

$H_q(x,0) = q(x)$

$$F_1(t) = \sum_q e_q \int dx H_q(x,t)$$

transverse center of mass R

$$\left| p^+, \mathbf{R} = \mathbf{0}, \lambda \right\rangle \equiv \mathcal{N} \int \frac{d^2\mathbf{p}}{(2\pi)^2} \left| p^+, \mathbf{p}, \lambda \right\rangle$$

$$\hat{O}_q(x, \mathrm{b}) \equiv \int \frac{dx^-}{4\pi} q_+^\dagger \left(-\frac{x^-}{2}, \mathrm{b} \right) q_+ \left(\frac{x^-}{2}, \mathrm{b} \right) e^{ixp^+x^-}$$

$$H_q(x,t) = \int \frac{dx^-}{4\pi} \langle p^+, \mathrm{p}', \lambda | \bar{q}(-\frac{x^-}{2}, 0) \gamma^+ q(\frac{x^-}{2}, 0) | p^+, \mathrm{p}, \lambda \rangle e^{ixp^+x^-}$$

$$\hat{O}_q(x, \mathbf{b}) \equiv \int \frac{dx^-}{4\pi} q_+^\dagger \left(-\frac{x^-}{2}, \mathbf{b} \right) q_+ \left(\frac{x^-}{2}, \mathbf{b} \right) e^{ixp^+x^-}$$

$$q(x, \mathbf{b}) \equiv \left\langle p^+, \mathbf{R} = \mathbf{0}, \lambda \right| \hat{O}_q(x, \mathbf{b}) \left| p^+, \mathbf{R} = \mathbf{0}, \lambda \right\rangle .$$

Burkardt

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

Integrate on x, Left: sets $x^- = 0$ → $q_+^\dagger(0,b)\, q_+(0,b)$

DENSITY; right 2 Dim. Fourier T. of F_1

RESULT

$$\rho(b) \equiv \sum_q e_q \int dx\, q(x,\mathbf{b}) = \int \frac{d^2q}{(2\pi)^2} F_1(Q^2 = \mathbf{q}^2) e^{i\,\mathbf{q}\cdot\mathbf{b}}.$$

Density

Soper '77

$$\rho(b) = \int_0^\infty \frac{dQ\,Q}{2\pi} J_0(Qb) \frac{G_E(Q^2) + \tau G_M(Q^2)}{1+\tau}$$

$\tau = Q^2 / 4M^2$

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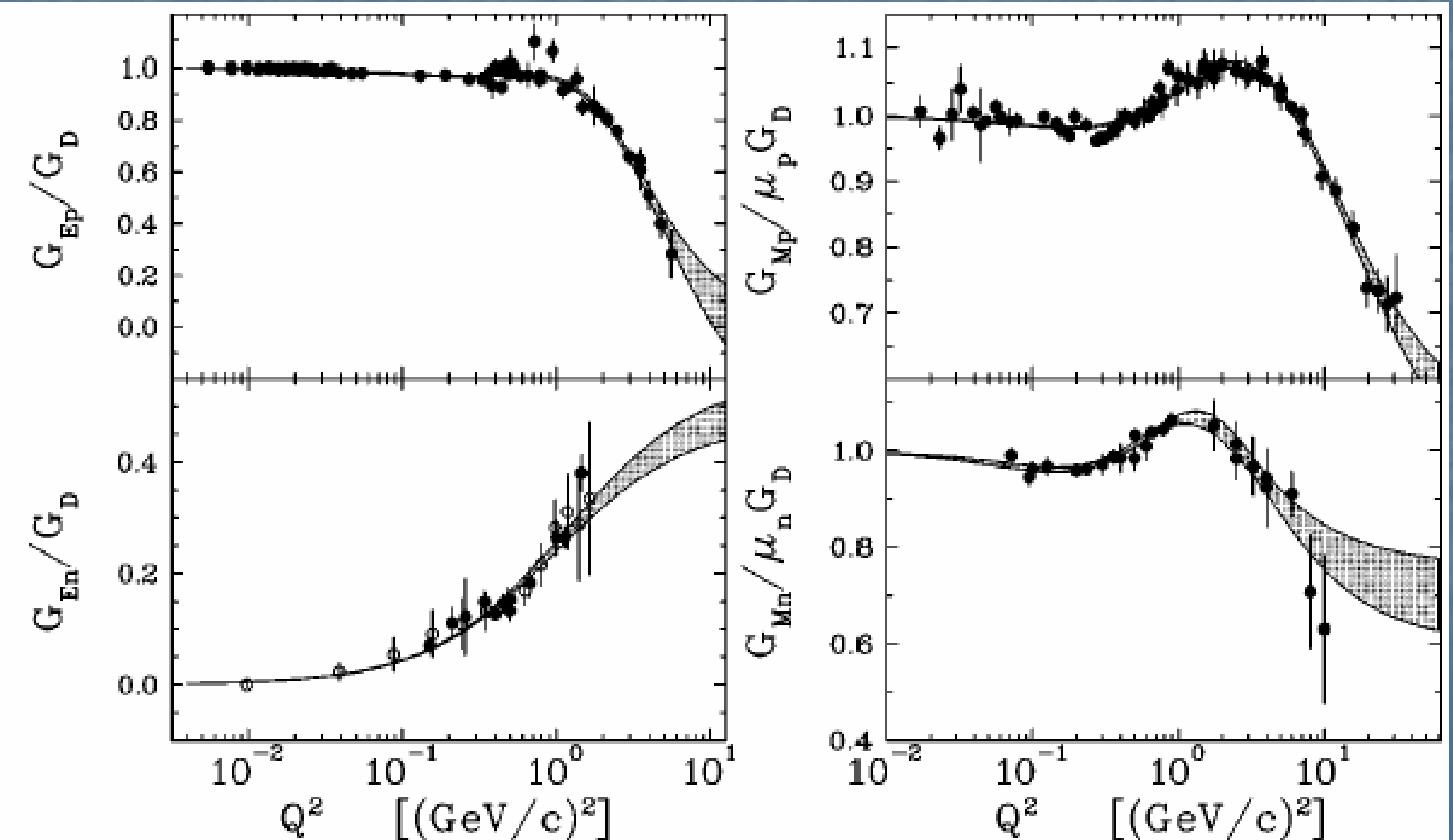
Simple parametrization of nucleon form factors

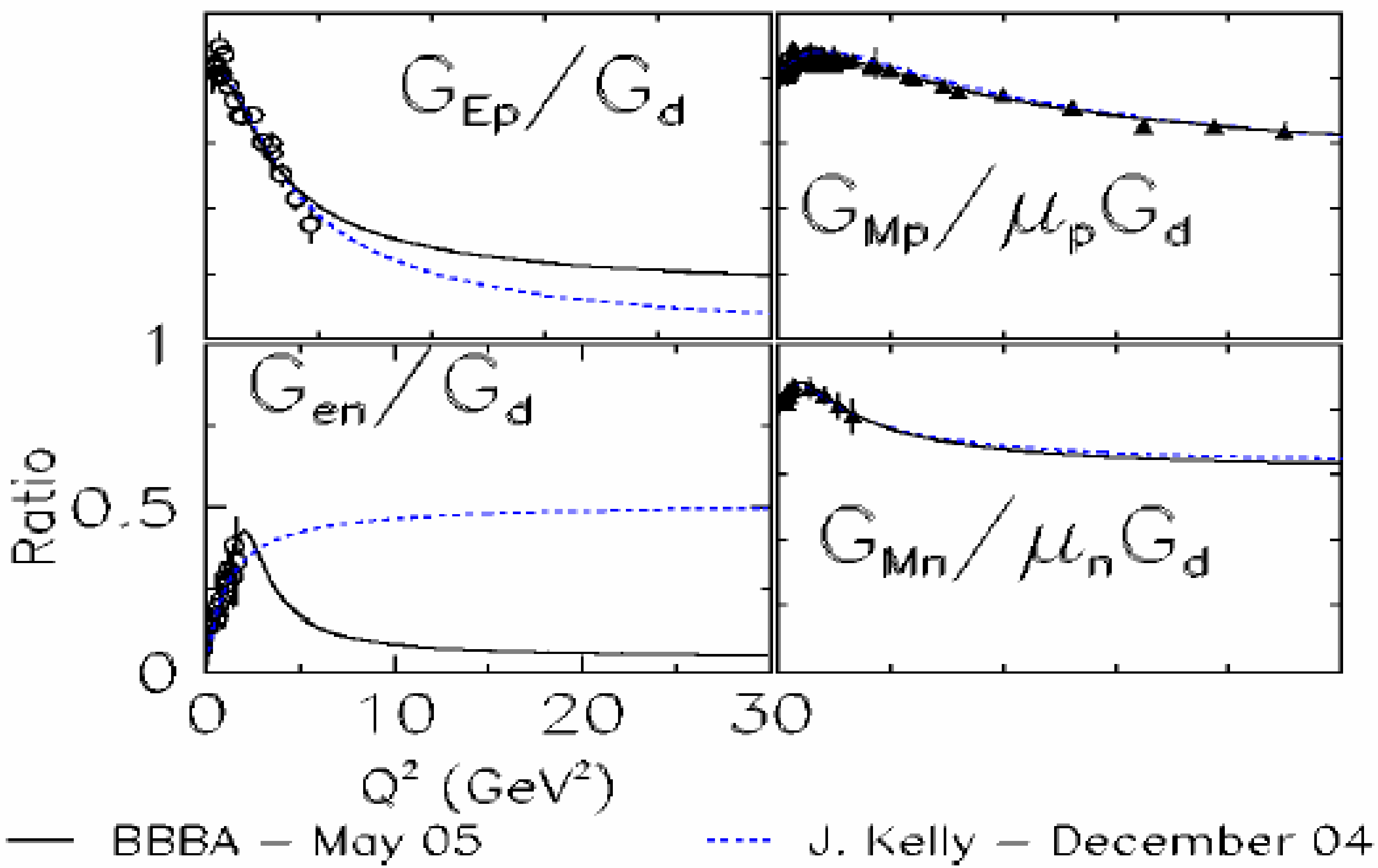
J. J. Kelly



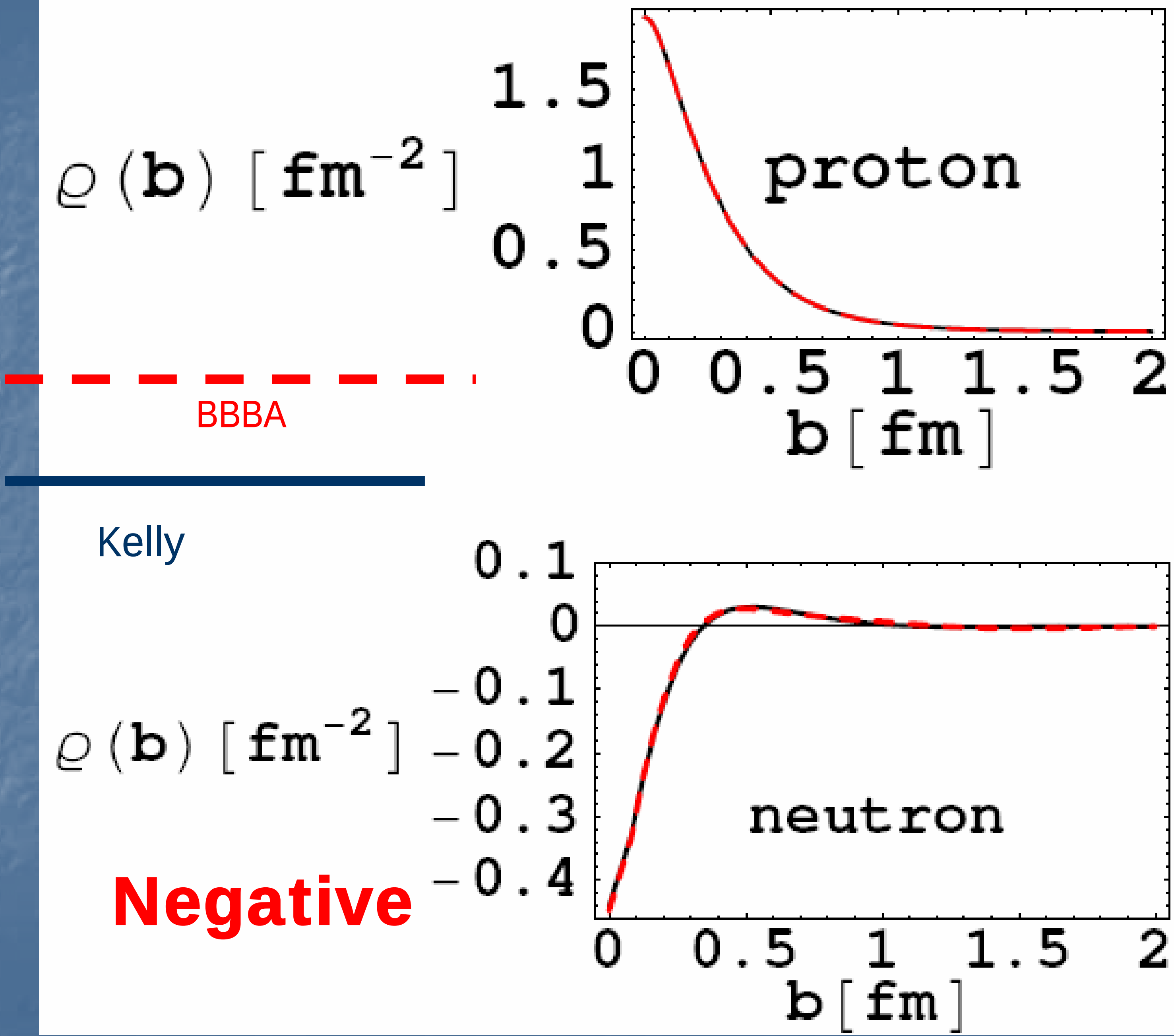
A New Parameterization of the Nucleon Elastic Form Factors

R. Bradford,[a] A. Bodek,[a] H. Budd,[a] and J. Arrington[b]

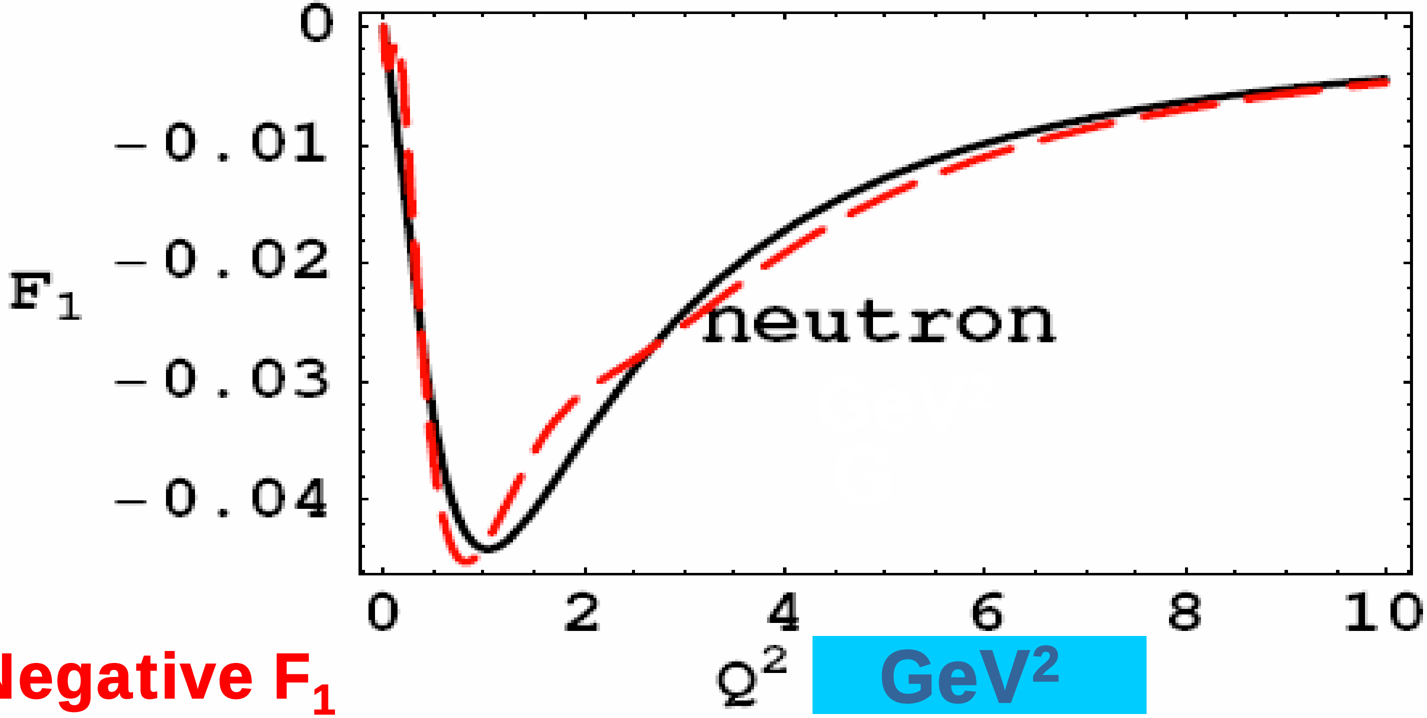
hep-ex/0602017



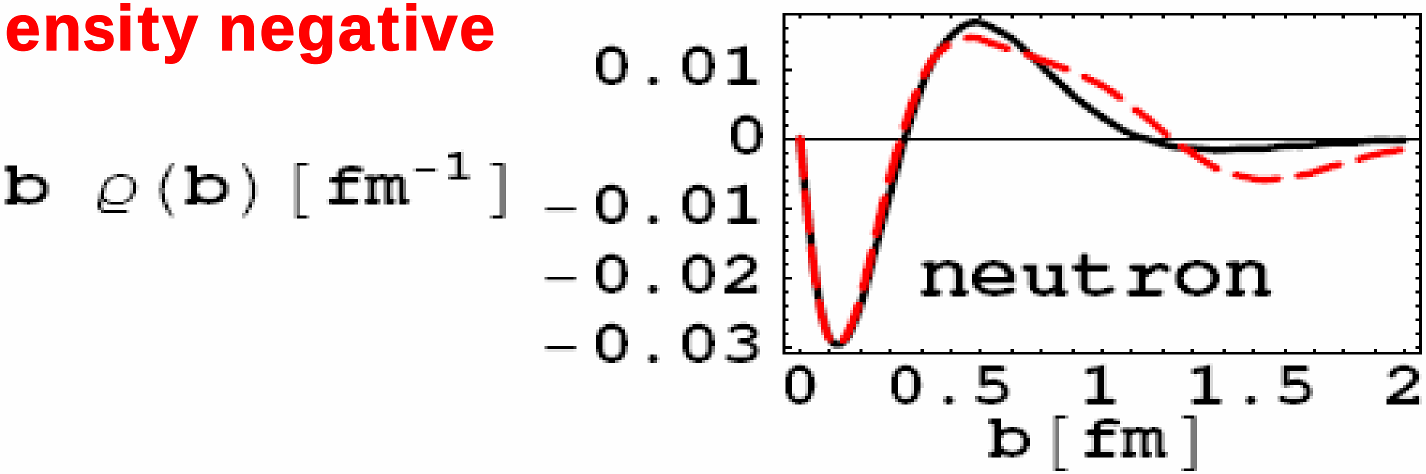
Results



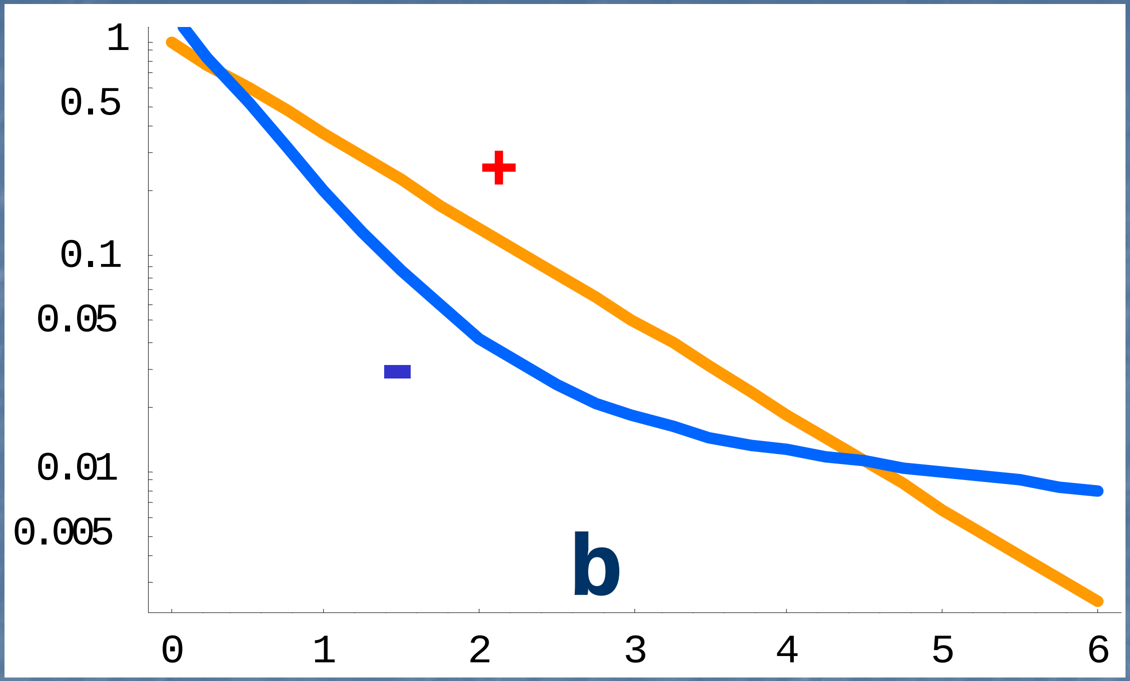
Negative



Negative F_1 means central density negative



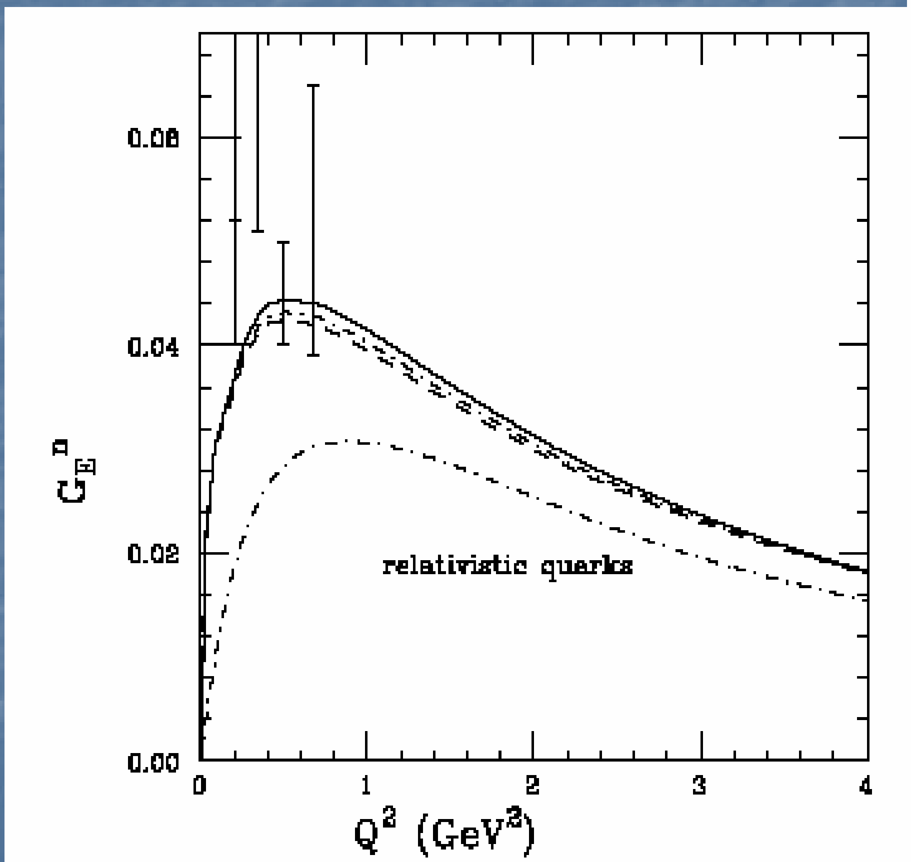
Neutron Interpretation

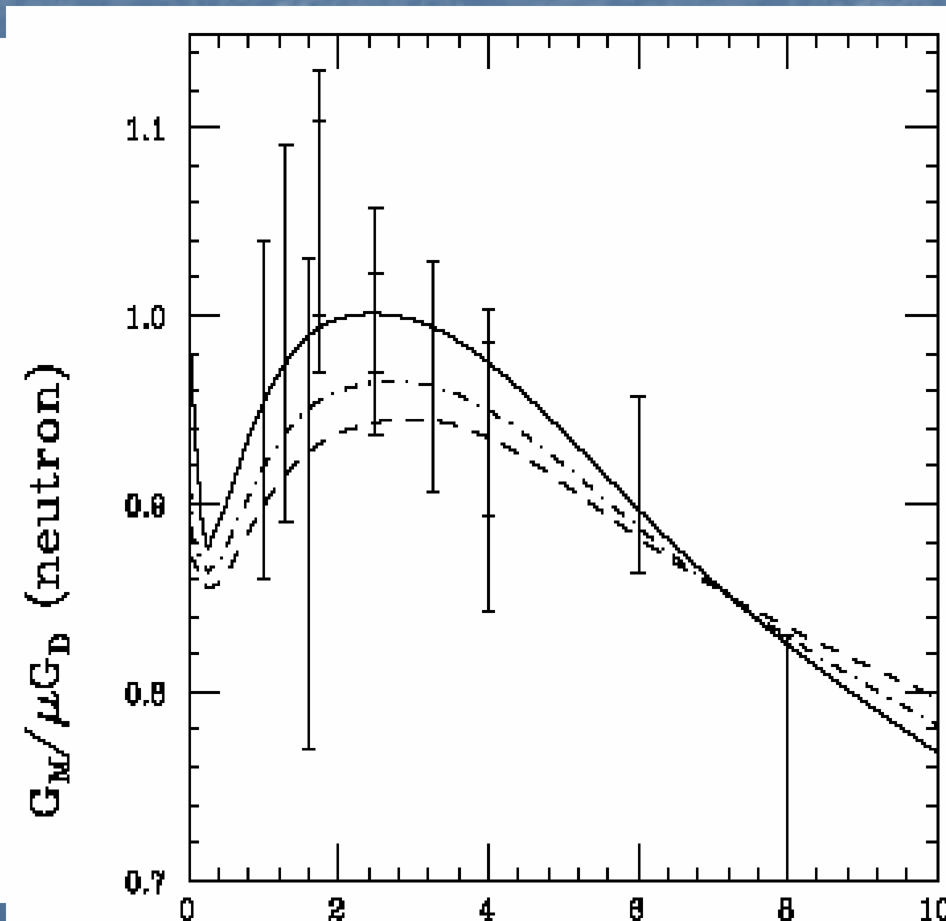


? π^- at short distance ?

Neutron Form Factors in LFCBM

Miller 2002

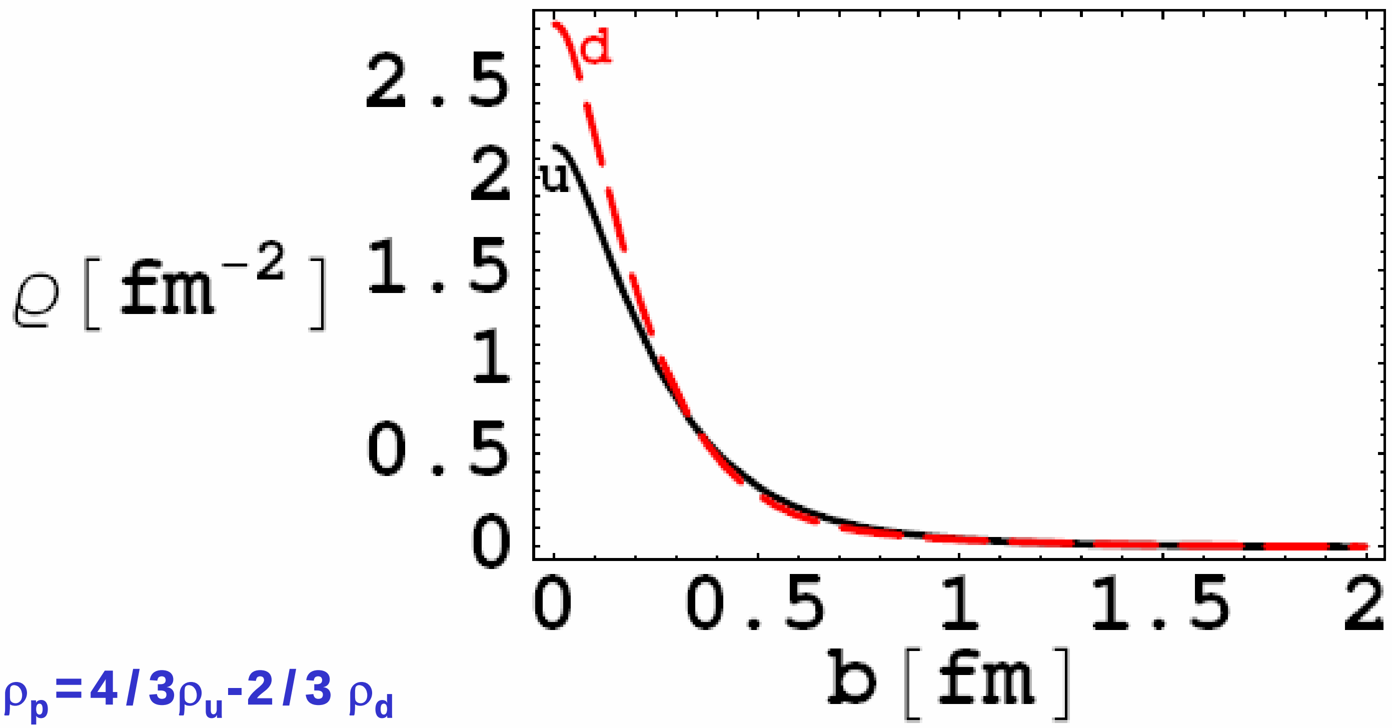




These give negative F_1

Charge symmetry: u in proton is d in neutron, d in proton is u in neutron

$\rho_u=\rho_p-\rho_n/2 \quad \rho_d=\rho_p-2\rho_n$



$\rho_p=4/3\rho_u-2/3\ \rho_d$

?Quark interpretation?

- b=0, high transverse momentum, low Bjorken x
- low x, sea
- u ū is suppressed by Pauli principal, Signal & Thomas

Summary

- Model independent information on charge density

$$\rho(b) \equiv \sum_q e_q \int dx\, q(x, \mathbf{b}) = \int d^2q F_1(Q^2 = \mathbf{q}^2) e^{i\,\mathbf{q}\cdot\mathbf{b}}$$

• Central charge density of neutron is negative

• Pion cloud at large b