Measuring quark confining forces in the proton?

Forces & pressure are mechanical properties of matter, how to probe them at fm scale?

→ **Through Gravity!**





March 29, 1919

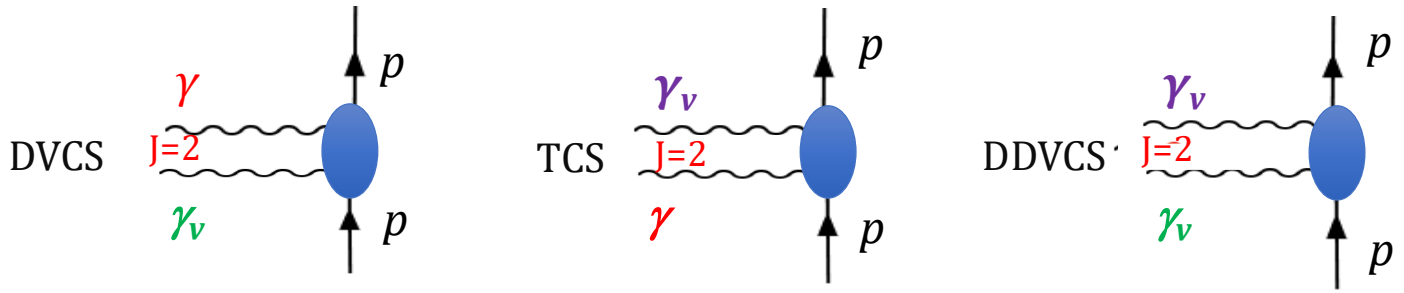
- Gravity is **far too** weak to probe the proton directly.

EMT: $\langle p_2|\hat{T}^q_{\mu\nu}|p_1\rangle = \bar{U}(p_2)\left[\, M_2(t)\,\frac{P_\mu P_\nu}{M} + J(t)\,\frac{(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M} + d_1(t)\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right] U(p_1)$

Gravitational FF: **Mass & energy** **Angular momentum** **Shear forces & pressure**

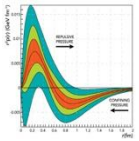
- X. Ji, M. Polyakov, others

Relationship to the GPDs H & E: $\int dx\, x\,[H(x,\xi,t)+E(x,\xi,t)] = 2J(t)$ $\int dx\, xH(x,\xi,t) = M_2(t) + \frac{4}{5}\xi^2 d_1(t),$

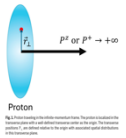


→ **We have the opportunity to use electromagnetic probes to investigate the strong forces responsible for confinement.**

Transverse confining quark forces in IMF



Pressure and shear stress have been obtained in the Breit-frame (BEG).

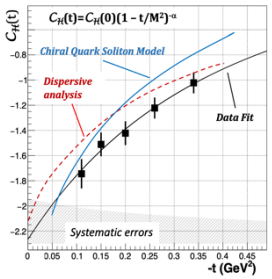


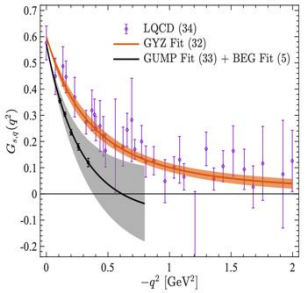
To measure the **transverse** confining forces we need to know them in the IMF.

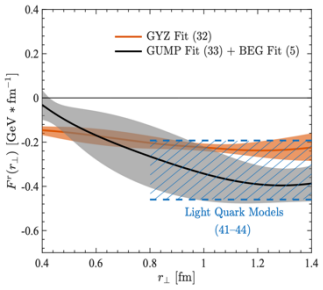
X. Ji, G. Miller, C. Yang, research 9 1369 (2026)

$$G_{s,q}(q^2) = A_q(q^2) + B_q(q^2)\frac{q^2}{4M^2} - C_q(q^2)\frac{3q^2}{M^2} \quad (q^2 = t)$$

Combines M_2 and J; $C_q = 1/5\, d_1$, assumption about A_q







Extrapolating the BEG D-term to –t = 0.02 GeV², JMY claim "Evidence for quark confinement in the proton".

The r_t-independence of the transverse force is potential signature of the onset of confinement.

Required measurements?

- Probing confining forces → large –t range measurements of CFFs & GPDs, especially important is reach to **smallest -t.**
- -t = 0.11 GeV² relates to ~0.6 fm; proton: $\langle r \rangle_{mech}$ ~0.65fm
- **-t = 0.02 GeV² probes ~1.4 fm**

Equipment needed for a full DVCS/TCS program?

- High energy resolution e.m. calorimeter for DVCS/BH photons in range Θ_γ ~2.5°-5° for γ/π^0 separation to ~9GeV
- Large polar angle (40° – 65°) reconstruction of protons in momentum range of ~ 150 – 500 MeV/c.
- For TCS a large angle detector for electron/positron ID in the CD range to backward angles.

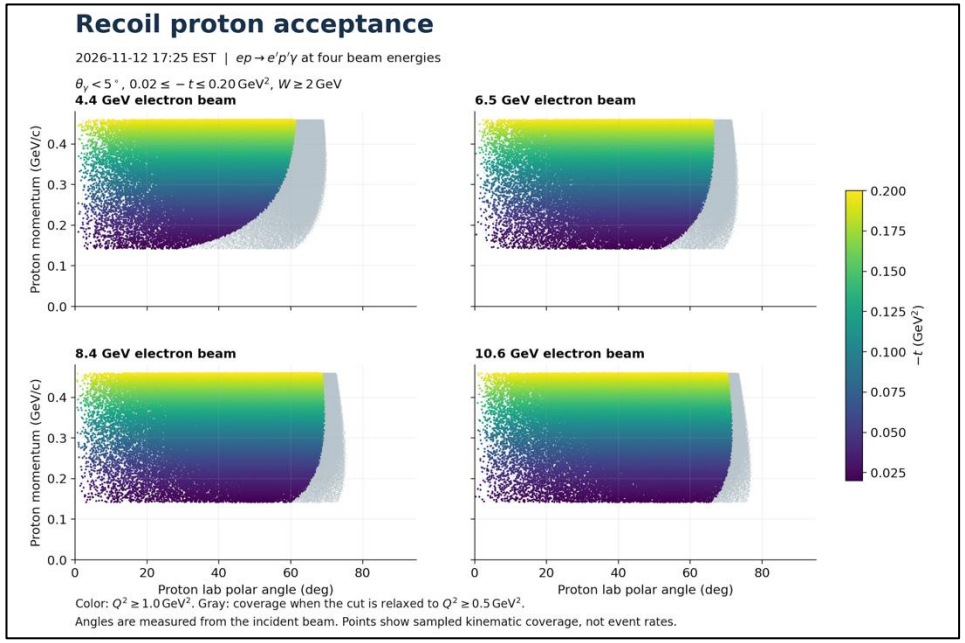
Equipment needed for the DDVCS program?

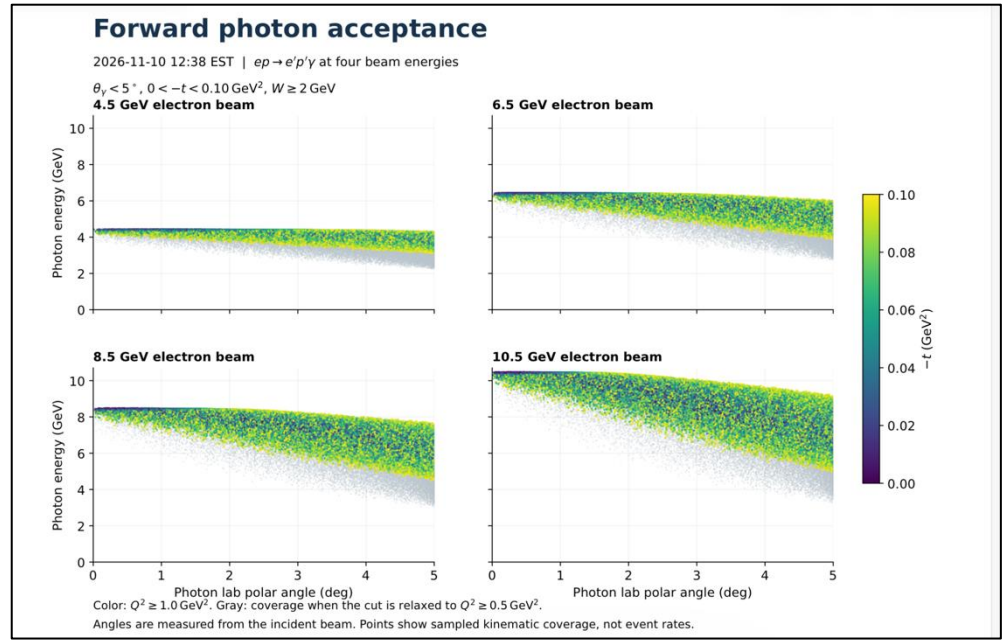
- Modified μCLAS12 detector for detection of μ^+ μ^- and specialized other detectors and shielding, already approved.

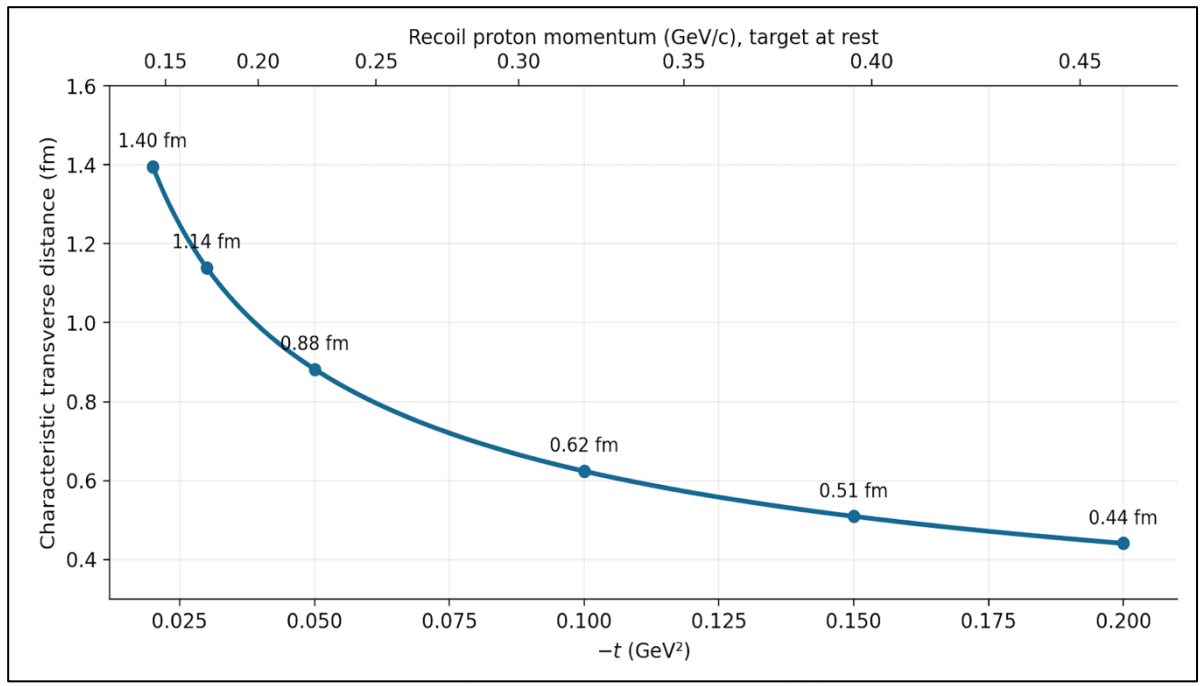
→ **We have the theoretical framework, important first experimental results, know what is needed in addition.**

This program should be one of the compelling scientific goals of CEBAF 2037

Support slides for discussion


Recoil proton acceptance
2026-11-12 17:25 EST | $ep \to e'p'\gamma$ at four beam energies
$\theta_\gamma < 5^\circ$, $0.02 \le -t \le 0.20\,\mathrm{GeV}^2$, $W \ge 2\,\mathrm{GeV}$
4.4 GeV electron beam
6.5 GeV electron beam
8.4 GeV electron beam
10.6 GeV electron beam
Proton momentum (GeV/c)
Proton lab polar angle (deg)
$-t$ (GeV²)
Color: $Q^2 \ge 1.0\,\mathrm{GeV}^2$. Gray: coverage when the cut is relaxed to $Q^2 \ge 0.5\,\mathrm{GeV}^2$.
Angles are measured from the incident beam. Points show sampled kinematic coverage, not event rates.


Forward photon acceptance
2026-11-10 12:38 EST | $ep \to e'p'\gamma$ at four beam energies
$\theta_\gamma < 5^\circ$, $0 < -t < 0.10\,\mathrm{GeV}^2$, $W \ge 2\,\mathrm{GeV}$
4.5 GeV electron beam
6.5 GeV electron beam
8.5 GeV electron beam
10.5 GeV electron beam
Photon energy (GeV)
Photon lab polar angle (deg)
$-t$ (GeV²)
Color: $Q^2 \ge 1.0\,\mathrm{GeV}^2$. Gray: coverage when the cut is relaxed to $Q^2 \ge 0.5\,\mathrm{GeV}^2$.
Angles are measured from the incident beam. Points show sampled kinematic coverage, not event rates.


Recoil proton momentum (GeV/c), target at rest
1.40 fm
1.14 fm
0.88 fm
0.62 fm
0.51 fm
0.44 fm
Characteristic transverse distance (fm)
$-t$ (GeV²)

For $Q^2 \geq 1.0\ \mathrm{GeV}^2$ and $W \geq 2.0\ \mathrm{GeV}$, the approximate sampled coverage is:

Beam energy (GeV)	Photon energy below 5° (GeV)	Recoil momentum (MeV/c)	Recoil lab angle reaches
4.5	3.1–4.4	121–321	59°
6.5	3.9–6.5	83–321	66°
8.5	4.5–8.5	63–321	69°
10.5	5.0–10.5	51–321	72°