Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab

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University of Richmond, Richmond, VA 23173

Outline

1. Scientific Motivation
2. Necessary Background
3. What We Hope to Learn.
4. The Measurements
5. Summary and Conclusions

Tlaxcala City
Scientific Motivation - What We Hope to Learn.

- Nucleon elastic electromagnetic form factors (EEFFs) describe the distribution of charge and magnetization in the nucleon.
- Reveal the internal landscape of the nucleon and nuclei.
- Rigorously test QCD in the non-perturbative regime.
  - Nuclear models, constituent quarks,…
  - Lattice QCD.
- Map the transition from the hadronic picture to QCD.
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EEFFs have played an essential role in nuclear and nucleon structure for more than a half century.
Some Necessary Background

- EEFFs cross section described with Dirac ($F_1$) and Pauli ($F_2$) form factors

\[
\frac{d\sigma}{d\Omega} = \sigma_{Mott} \left[ (F_1^2 + \kappa^2 \tau F_2^2) + 2\tau (F_1 + \kappa F_2)^2 \tan^2 \left(\frac{\theta}{2}\right) \right]
\]

where

\[
\sigma_{Mott} = \frac{\alpha^2 E' \cos^2 \left(\frac{\theta}{2}\right)}{4E^3 \sin^4 \left(\frac{\theta}{2}\right)}
\]

and $\kappa$ is the anomalous magnetic moment, $E$ ($E'$) is the incoming (outgoing) electron energy, $\theta$ is the scattered electron angle and $\tau = Q^2 / 4M^2$.

- For convenience use the Sachs form factors.

\[
\frac{d\sigma}{d\Omega} = \frac{\sigma_{Mott}}{\epsilon (1 + \tau)} \left( \epsilon G_E^2 + \tau G_M^2 \right)
\]

where

\[
G_E = F_1 - \tau F_2 \quad \text{and} \quad G_M = F_1 + F_2 \quad \text{and} \quad \epsilon = \left[ 1 + 2(1 + \tau) \tan^2 \frac{\theta}{2} \right]^{-1}
\]
Where We Are Now.

- $G_M^P$ reasonably well known over large $Q^2$ range.
- The ratio $G_E^P / G_M^P$ from recoil polarization measurements diverged from previous Rosenbluth separations.
  - Two-photon exchange (TPE).
  - Effect of radiative corrections.
- Neutron magnetic FF $G_M^n$ still follows dipole.
- High-$Q^2$ $G_E^n$ opens up flavor decomposition.
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Advances driven by:

- high luminosity beams
- large acceptance detectors
- polarized beams, targets, detectors
Where We Are Now.

- Vector Meson Dominance and dispersion analyses fit all four EEFFs, but use many parameters.
- Constituent Quark Models highlight relativity, but don’t capture all of QCD.
- EEFFs are the first moments of the GPDs.
- EEFFs are an early test of lattice QCD because isovector form does not have disconnected diagrams.
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P.E. Shanahan et al.
PRD 90, 034502 (2014)

CSM, QCDSF/UKQCD Collaborations

Blue - lQCD result
Red - data parameterization
Green - dipole fit to calculation

Jerry Gilfoyle, Hadron2014
Where We Are Going - Dyson-Schwinger Eqs

- Equations of motion of quantum field theory.
  - Infinite set of coupled integral equations.
  - Inherently relativistic, non-perturbative, connected to QCD.
  - Deep connection to confinement, dynamical chiral symmetry breaking.
  - Infinitely many equations, gauge dependent $\rightarrow$ Choose well!

- Recent results (Cloët et al).
  - Model the nucleon dressed quark propagator as a quark-diquark.
  - Damp the shape of the mass function $M(p)$.

![Graph showing $M(p)$ vs $p$ for different values of $\alpha$.](PRL 111, 101803 (2013))
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Position of zero in $\mu_p G_E^p / G_M^p$ and $\mu_n G_E^n / G_M^n$ sensitive to shape of $M(p)$!
Where We Are Going - Flavor Decomposition

- With all four EEFFs we can unravel the contributions of the \( u \) and \( d \) quarks.
- Assume charge symmetry, no \( s \) quarks and use (Miller et al. Phys. Rep. 194, 1 (1990))
  \[
  F_{1(2)}^u = 2F_{1(2)}^p + F_{1(2)}^n \\
  F_{1(2)}^d = 2F_{1(2)}^n + F_{1(2)}^p
  \]

Evidence of di-quarks?
\( d \)-quark scattering probes the diquark.
Cloet et al. PRC, 90 045202 (2014)
Agreement with Nambu-Jona-Lasinio model encouraging.
The JLab program will double our reach in \( Q^2 \) to \( \approx 8 \) GeV\(^2\).
With all four EEFFs we can unravel the contributions of the $u$ and $d$ quarks.


$$F_{u,d}^{1(2)} = 2F_{p}^{1(2)} + F_{n}^{1(2)}$$

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- Evidence of di-quarks? $d$-quark scattering probes the diquark.

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\[ F_{1(2)}^u \neq F_{1(2)}^d \]

The JLab program will double our reach in $Q^2$ to $\approx 8 \text{ GeV}^2$. 

\[ \frac{Q^4 F_{2u}^u}{\kappa_u} \quad \frac{Q^4 F_{2d}^d}{\kappa_d} \]

Cloet et al.
PRC, 90 045202 (2014)
Based on connections between light-front dynamic, it’s holographic mapping to anti-de Sitter space, and conformal quantum mechanics.

Recent paper by Sufian et al. (Phys. Rev. D95, 01411 (2017)) included calculations of the electromagnetic form factors that include higher order Fock components $|qqqqq\rangle$.

Obtain good agreement with all the form factor data with only three parameters, e.g. $\mu_n G^n_E / G^n_M$. 
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Obtain good agreement with all the form factor data with only three parameters, e.g. $\mu_n G_E^n / G_M^n$.

Major difference with DSE approach!
## Where We Are Going - New Experiments

### The JLab Lineup

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Method</th>
<th>Target</th>
<th>$Q^2 (\text{GeV}^2)$</th>
<th>Hall</th>
<th>Beam Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_M^p$</td>
<td>Elastic scattering</td>
<td>$LH_2$</td>
<td>7 – 15.5</td>
<td>A</td>
<td>24</td>
</tr>
<tr>
<td>$G_E^p/G_M^p$</td>
<td>Polarization transfer</td>
<td>$LH_2$</td>
<td>5 – 12</td>
<td>A</td>
<td>45</td>
</tr>
<tr>
<td>$G_M^n$</td>
<td>$E - p/e - n$ ratio</td>
<td>$LD_2 - LH_2$</td>
<td>3.5 – 13.0</td>
<td>B</td>
<td>30</td>
</tr>
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<td>A</td>
<td>25</td>
</tr>
<tr>
<td>$G_E^n/G_M^n$</td>
<td>Double polarization asymmetry</td>
<td>polarization $^3\text{He}$</td>
<td>5 – 8</td>
<td>A</td>
<td>50</td>
</tr>
<tr>
<td>$G_E^n/G_M^n$</td>
<td>Polarization transfer</td>
<td>$LD_2$</td>
<td>4 – 7</td>
<td>C</td>
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<td>4.5</td>
<td>A</td>
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</table>

* Data collection is complete.

PAC approval for 229 days of running in the first five years.

All experiments build on successful ones from the 6-GeV era.
How We Will Get There: Jefferson Lab

Continuous Electron Beam Accelerator Facility (CEBAF)

- Superconducting Electron Accelerator (currently 338 cavities), 100% duty cycle.
- $E_{max} = 11$ GeV (Halls A, B, and C) and 12 GeV (Hall D), $\Delta E/E \approx 2 \times 10^{-4}$, $I_{summed} \approx 90 \mu A$, $P_e \geq 80\%$. 

Jerry Gilfoyle, Hadron2014
The Experiments - New Detectors

Hall A - High Resolution Spectrometer (HRS) pair, SuperBigBite (SBS), neutron detector, and specialized installation experiments.

Hall C - New Super High Momentum Spectrometer to paired with the existing High Momentum Spectrometer.

Hall B - CLAS12 large acceptance spectrometer operating at high luminosity with toroid (forward detector) and solenoid (central detector).

Hall D - A new large acceptance detector based on a solenoid magnet for photon beams is under construction.
Proton Magnetic Form Factor - $G_M^p$

- Precise measurement of $ep$ elastic cross section and extract $G_M^p$.
- Both HRSs in electron mode.
- Beamtime: 24 days.
- $Q^2 = 7.0 - 15.5 \text{ GeV}^2 (1.0, 1.5 \text{ GeV}^2 \text{ steps})$.
- Significant reduction in uncertainties:

<table>
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<tr>
<th></th>
<th>$d\sigma/d\Omega$</th>
<th>$G_M^p$</th>
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<tr>
<td>Point-to-Point</td>
<td>1.0-1.3</td>
<td>0.5-0.6</td>
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<td>Normalization</td>
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<td>Theory</td>
<td>1.0-2.0</td>
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- Two-Photon Exchange is a major source of uncertainty $\rightarrow$ vary $\epsilon$ to constrain.
- Sets the scale of other EEFFs.
- Completed data collection this year.

E. Christy, Hall A Summer Meeting 2017
Proton Form Factor Ratio $G_P^E / G_P^M$

- E12-07-109 (GEp(5)) in Hall A (Brash, Jones, Perdrisat, Pentchev, Cisbani, Punjabi, Khandaker, Wojtsekhowski).
- Polarization transfer using $H(\vec{e}, e'\vec{p})$:

$$\frac{G_P^E}{G_P^M} = -\frac{P_t}{P_l} \frac{E + E'}{2M} \tan\left(\frac{\theta_e}{2}\right)$$

- Electron arm: EM calorimeter (BigCal).
- Proton arm: new, large-acceptance magnetic spectrometer (SBS) with double polarimeter, and hadron calorimeter.
- Beamtime: 45 days.
- Kinematics and Uncertainties:

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- Combined with GEp(4).
- Rated high impact by JLab PAC.
- Running expected in 3-4 years.
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Neutron Magnetic Form Factor $G^n_M - 1$

- E12-07-104 in Hall B (Gilfoyle, Hafidi, Brooks).

- Ratio Method on Deuterium:

$$R = \frac{\frac{d\sigma}{d\Omega} [^2H(e,e' n)_{QE}]}{\frac{d\sigma}{d\Omega} [^2H(e,e' p)_{QE}]}$$

$$= a \times \frac{\sigma_{Mott} \left( \frac{(G_E^n)^2 + \tau (G_M^n)^2}{1+\tau} + 2\tau \tan^2 \frac{\theta_e}{2} (G_M^n)^2 \right)}{\frac{d\sigma}{d\Omega} [^1H(e,e' p)]}$$

where $a$ is nuclear correction.

- Precise neutron detection efficiency needed to keep systematics low.

- tagged neutrons from $p(e, e' \pi^+ n)$.

- Dual $LD_2 - LH_2$ target.

- Kinematics: $Q^2 = 3.5 - 13.0 \ (GeV/c)^2$.

- Beamtime: 30 days.

- Systematic uncertainties $< 2.5\%$ across full $Q^2$ range.

- Running expected in 2019.
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Beamtime: 30 days.

Systematic uncertainties < 2.5% across full \( Q^2 \) range.

Running expected in 2019.
Neutron Magnetic Form Factor $G_M^n - 2$

- E12-09-019 in Hall A (Quinn, Wojtsekhowski, Gilman).
- Ratio Method on Deuterium as in Hall B:
  $$R = \frac{d\sigma}{d\Omega}[^2\text{H}(e, e'n)_{QE}]/\frac{d\sigma}{d\Omega}[^2\text{H}(e, e'p)_{QE}]$$
- Electron arm: SuperBigBite spectrometer.
- Hadron arm: hadron calorimeter (HCal).
- Neutron detection efficiency:
  - Use $p(\gamma, \pi^+)n$ for tagged neutrons.
  - End-point method.
- Kinematics: $Q^2 = 3.5 - 13.5 \text{ (GeV/c)}^2$.
- Beamtime: 25 days.
- Systematic uncertainties < 2.1%.
- Two $G_M^n$ measurements ‘allow a better control for the systematic error’ (PAC34).
- Expected in next 2-3 years.
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Neutron Form Factor Ratio $G_E^n/G_M^n - 1$

- E12-09-016 in Hall A (Cates, Wojtsekhowski, Riordan).
- Double Polarization Asymmetry: Get $A_{en}^V$ from $^3\text{He}(\vec{e}, e'n)pp$.
- Longitudinally polarized electron beam.
- $^3\text{He}$ target polarized perpendicular to the momentum transfer.
- Electron arm: Super BigBite spectrometer.
- Neutron arm: hadron calorimeter HCal (overlap with GEp(5) and Hall A $G_M^n$).
- Beamtime: 50 days.
- Kinematics and Uncertainties:

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$$A_{en}^V = \frac{-2\sqrt{\tau(\tau + 1)\tan(\theta_e/2)\cos\phi^* \sin \theta^* G_E^n/G_M^n}}{(G_E^n/G_M^n)^2 + \tau/\epsilon} + \frac{-2\tau\sqrt{1 + \tau + (\tau + 1)^2 \tan^2(\theta_e/2)\tan(\theta_e/2)\cos\phi^*}}{(G_E^n/G_M^n)^2 + \tau/\epsilon}$$

where $\epsilon = 1/\left(1 + 2(1 + \tau)\tan^2\left(\frac{\theta_e}{2}\right)\right)$

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Jerry Gilfoyle, Hadron2014

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Neutron Form Factor Ratio $G_E^n/G_M^n - 2$

- E12-11-009 in Hall C (Sawatzky, Arrington, Kohl, Semenov).
- Polarization transfer using $^2\text{H}(\vec{e}, e'\vec{n})p$:
  \[
  \frac{G_E^n}{G_M^n} = -\frac{P_t}{P_l} \frac{E + E'}{2M} \tan \left( \frac{\theta_e}{2} \right)
  \]
- Electron arm: Super High Momentum Spectrometer (SHMS).
- Neutron arm: neutron polarimeter with tapered-gap neutron-spin-precession magnet and proton recoil detection.
- Kinematics: $Q^2 = 3.95, 6.88 \ (\text{GeV/c})^2$.
- Beamtime: 50 days.
- Systematic uncertainties about 2-3%.
- Statistical uncertainties about 10-16%.
- Complementary to the $^3\text{He}$ experiment.
- Expected after 2020.
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  \]
- Electron arm: Super High Momentum Spectrometer (SHMS).
- Neutron arm: neutron polarimeter with tapered-gap neutron-spin-precession magnet and proton recoil detection.
- Kinematics: $Q^2 = 3.95, 6.88$ (GeV/c)$^2$.
- Beamtime: 50 days.
- Systematic uncertainties about 2-3%.
- Statistical uncertainties about 10-16%.
- Complementary to the $^3\text{He}$ experiment.
- Expected after 2020.
Neutron Form Factor Ratio $G^n_E / G^n_M - 3$

- E12-17-004 in Hall C (Annand, Bellini, Kohl, Psikunov, Sawatzky, Wojtsekowsk).
- Polarization transfer using $^2\text{H}(\vec{e}, e' \vec{n})p$:
  \[
  \frac{G^n_E}{G^n_M} = -\frac{P_t}{P_l} \frac{E + E'}{2M} \tan \left( \frac{\theta_e}{2} \right)
  \]
- Electron arm: Super Big Bite Spectrometer.
- Neutron arm: HCal, neutron polarimeter, CDet coordinate detector, scintillation counter.
- Kinematics: $Q^2 = 4.5 \ (\text{GeV/c})^2$.
- Beamtime: 5 days.
- Systematic uncertainties about 3%.
- Statistical uncertainties about 8%.
- Complementary to the $^3\text{He}$ experiment.
- Expected in the next 2-3 years.
Neutron Form Factor Ratio $G^n_E/G^n_M - 3$

- E12-17-004 in Hall C (Annand, Bellini, Kohl, Psikunov, Sawatzky, Wojtsekhowski).
- Polarization transfer using $^2\text{H}(\bar{e}, e'\bar{n})p$:
  \[
  \frac{G^n_E}{G^n_M} = -\frac{P_t E + E'}{P_I 2M} \tan \left(\frac{\theta_e}{2}\right) 
  \]
- Electron arm: Super Big Bite Spectrometer.
- Neutron arm: HCal, neutron polarimeter, CDet coordinate detector, scintillation counter.
- Kinematics: $Q^2 = 4.5 \text{ (GeV/c)}^2$.
- Beamtime: 5 days.
- Systematic uncertainties about 3%.
- Statistical uncertainties about 8%.
- Complementary to the $^3\text{He}$ experiment.
- Expected in the next 2-3 years.
Summary and Conclusions

- Large gains over the last decade in physics understanding of the EEFFs built on new technologies and capabilities.
- Major changes in our understanding of nucleon structure.
- At JLab we have begun a broad assault on the EEFFs and will significantly expand the physics reach of our understanding.
- Discovery potential in mapping out nucleon structure and understanding QCD.
Additional Slides
Additional form factor studies after the 12 GeV Upgrade.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Spokesperson</th>
<th>Title</th>
<th>Hall</th>
<th>Beamtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR12-06-101</td>
<td>G. Huber</td>
<td>Measurement of the charged pion form factor to high $Q^2$</td>
<td>C</td>
<td>52 days</td>
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<tr>
<td>PR12-09-003</td>
<td>R. Gothe</td>
<td>Nucleon resonance studies with CLAS12</td>
<td>B</td>
<td>40 days</td>
</tr>
</tbody>
</table>
### High-Impact Experiments from JLab PAC

**PAC Days**
- Boldface = days designated High Impact
- Parentheses = days not counting toward High Impact total

**Row Color**
- Yellow = High Impact
- Green = backup experiment

<table>
<thead>
<tr>
<th>Exp#</th>
<th>Exp name</th>
<th>Hall</th>
<th>Run Group/ Days</th>
<th>PAC Days</th>
<th>PAC grade</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td><strong>TOPIC 1 : SPECTROSCOPY</strong></td>
<td></td>
<td></td>
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<tr>
<td>F2-12-09</td>
<td>BlueX : Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons</td>
<td>D</td>
<td>(120) approved</td>
<td>+90</td>
<td>A</td>
<td>GlueX - expected half commissioning/half physics +30 (commissioning days)</td>
</tr>
<tr>
<td><strong>TOPIC 2 : FORM FACTORS</strong></td>
<td></td>
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<tr>
<td>F2-12-12</td>
<td>Measurement of the Charged Pion Form Factor to High Q2</td>
<td>C</td>
<td>52</td>
<td>A</td>
<td>Requires fully commissioned SM8S</td>
<td></td>
</tr>
<tr>
<td>F2-01-11</td>
<td>QEep/Gep - Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 GeV/2 Using Recoil Polarization Method</td>
<td>A</td>
<td>45</td>
<td>A</td>
<td>Requires SBS and high-power cryo target</td>
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</tr>
<tr>
<td>F2-11-10</td>
<td>High Precision Measurement of the Proton Charge Radius</td>
<td>B</td>
<td>15</td>
<td>A</td>
<td>Non-CLA12 experiment, Pad</td>
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<tr>
<td><strong>TOPIC 3 : PDFs</strong></td>
<td></td>
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<tr>
<td>F2-06-11</td>
<td>BONuS : The Structure of the Free Neutron at Large 4-Bjorken X</td>
<td>B</td>
<td>F48</td>
<td>(48) approved</td>
<td>+21</td>
<td>A</td>
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<tr>
<td>F2-10-10</td>
<td>MARATHON : Measurement of the F2H/F2p, d/u Ratios and A=3 NMC-B in DS of the Tritium and Helium Mirror Nucleus</td>
<td>A</td>
<td>Tritium target group/hh</td>
<td>1</td>
<td>+21</td>
<td>A</td>
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<tr>
<td>F2-08-11</td>
<td>A1n Hall-C-3He : Meas. of Neutron Spin Asymmetry A/n in the Velocity/Quantum Region Using an 11 GeV Beam and a Polarized 9He Target in Hall C</td>
<td>C</td>
<td>36</td>
<td>A</td>
<td>Requires high luminosity 9He</td>
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<td><strong>TOPIC 4 : TMDs</strong></td>
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<tr>
<td>C2-11-11</td>
<td>TMD CLAS-HDice : SIDS on Transversely polarized target</td>
<td>B</td>
<td>Q/15</td>
<td>110</td>
<td>A</td>
<td>Requires transversely polarized HDice with electron beam</td>
</tr>
<tr>
<td>F2-09-11</td>
<td>Dilhadron CLAS-HDice : Measurement of transversity with dilution production in SIDS with transversely polarized target</td>
<td>B</td>
<td>Q/15</td>
<td>(110) concurrent</td>
<td>A</td>
<td>Requires transversely polarized HDice with electron beam C1 Proposal</td>
</tr>
<tr>
<td>F2-09-11</td>
<td>TMD CLAS-H(Umpol) : Probing the Proton’s Quantum Dynamics in Semi-Inclusive Production at 12 GeV</td>
<td>B</td>
<td>A/38</td>
<td>(60) approved</td>
<td>+10</td>
<td>A</td>
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<td><strong>TOPIC 5 : NUCLEAR</strong></td>
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<tr>
<td>C2-09-11</td>
<td>DVCS Hall-A(H,uu,uu) : Measurements of Electron-Helicity Dependent Cross Sections of DVCS with CEBAF at 35 GeV</td>
<td>A</td>
<td>Early</td>
<td>DVCS &amp; CLAS/62</td>
<td>(10) approved</td>
<td>A</td>
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<tr>
<td>F2-10-05</td>
<td>DVCS CLAS-HDice : DVCS at 11 GeV with transversely polarized target using the CLAS12 Detector</td>
<td>B</td>
<td>Q/15</td>
<td>(110) concurrent</td>
<td>A</td>
<td>Requires transversely polarized HDice with electron beam C1 Proposal</td>
</tr>
<tr>
<td>F2-11-12</td>
<td>DVCS CLAS-D(U,uu,uu) : DVCS on the Neutron with CLAS12 at 11 GeV</td>
<td>B</td>
<td>B/60</td>
<td>(90) approved</td>
<td>A</td>
<td>Requires D target, central neutron detector ready in 2018 + Backup GD-P-E meas if HDice delayed</td>
</tr>
<tr>
<td><strong>TOPIC 6 : FUNDAMENTAL SYMMETRIES</strong></td>
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<tr>
<td>F2-11-06</td>
<td>HPS : Status of the Heavy-Photon Search Experiment at Jefferson Laboratory (Update on PR12_11_06)</td>
<td>B</td>
<td>H/185</td>
<td>(155) approved</td>
<td>+39</td>
<td>A</td>
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<tr>
<td>F2-10-02</td>
<td>APEX : Search for new Vector Boson A1 Decaying to e+e-</td>
<td>B</td>
<td>A/34</td>
<td>(34) approved</td>
<td>A</td>
<td>Requires new septum and target system</td>
</tr>
</tbody>
</table>
Additional Theory Results

- Cloët, Bentz, and Thomas calculate the EEFFs using a covariant and confining Nambu-Jona-Lasinio model (arXiv:1405.5542v1 [nucl-th]).
- Bound state amplitude from solution of relativistic Faddeev equation.
- Get diquark degrees of freedom.
- Pion cloud added as a perturbation of the quark core.
- No model parameters.
Lattice gauge theory is the only means of *ab initio* QCD calculations in the non-perturbative regime.

Computationally challenging.

EEFFs are an early test of IQCD.

The isovector form of the EEFFs is

\[
F_{1,2}^V = \frac{F_{1,2}^p - F_{1,2}^n}{2}
\]

where

\[
F_1 = \frac{\tau G_M + G_E}{1 + \tau}, \quad F_2 = \frac{G_M - G_E}{1 + \tau}
\]

and \(\tau = Q^2/4M^2\).

This form does not have computationally demanding disconnected diagrams.

Expect EEFF calculation in the next decade.
Other EEFF Measurements - Electron-Positron Colliders

- **BEPC II/BES III** - Continued running for next 7-9 years at higher energies to extend the reach of spectroscopic studies, search for exotics, ... See talks by Xiaobin Ji, Rong-Gang Ping, and Yinghui Guan.
- **SuperKEKB/Belle II** - Will also probe the precision frontier, flavor physics, CP violation, exotics, 4 and 7 GeV. Commissioning starts in early 2015.
- **Novosibirsk** - Super Charm/Tau Factory is planned to probe the precision frontier, exotics, 3-5 GeV, now in CDR phase.