A Proposal to PAC 53
Measurement of the Axial-Vector Form Factor using the p($\vec{e}$,n)ν_e Reaction at $Q^2 = 1$ GeV^2

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Abstract goes here

I. EXECUTIVE SUMMARY

We plan a sensitive measurement of the Axial-Vector Form Factor of the proton, $F_A(Q^2)$, at $Q^2 = 1$ GeV^2 using the reaction p($\vec{e}$, n)ν by detecting the recoil neutron with a Time-of-Flight detector while vetoing e-p elastic and pion photo-production using a large acceptance charged particle spectrometer.

A. Main physics goals

The goal of the measurement of the axial-vector form factor of the proton is to address the following: The cross section of the charge current process at Q^2 near a maximum of the Axial-Vector Form Factor currently has uncertainty of 30%, which is by far too large for required analysis of modern neutrino oscillation experiments [1].

We propose to measure the axial-vector form factor of the proton at Q^2 = 1 (GeV/c)^2 [2] [3].

B. The proposed measurements/observables

Using the reaction p($\vec{e}$, n)$\overline{\nu}_e$, the axial vector form factor of the proton will be measured at $Q^2 = 1$ GeV^2 with relative accuracy of 15%.

C. Specific requirements for detectors, targets, and beam

- 10-cm long liquid hydrogen target.
- 100 μA electron beam at energy 2.2 GeV with high longitudinal polarization.
- 500 hours of data taking.
- Neutron detection: The primary trigger will be a proton or neutron event in the neutron detector. A time-of-flight system with 980 counters similar to that currently used in CLAS12, capable of reaching $\leq$ 100 ps time resolution. The TOF system will be used to 1) measure the time of the trigger with respect to the beam bunch time to identify neutrons from νn and 2) to separate proton and neutron events by looking at the shower geometry in the 7 TOF layers. A sweeper magnet will be used upstream of this detector system to reduce random low-energy background and separate protons from neutrons at the detector.
- A Veto spectrometer consisting of the SBS magnet and 8 layers of GEM chambers from the Hall A SBS program will be used, along with the SBS HCal, to reject any events coincident with the primary trigger. The primary background processes are e-p elastic scattering, and pion production.

CONTENTS

II. SCOPE

The list in the proposal document :

- Collaboration
- Executive
- Abstract
- Introduction
- Physics - Cross section code; AVFF in GPDs, DSE, lQCD, ν-nuclei
- Concept - veto EM processes efficiently; TOF; sweeper, high energy triggers
- Layout - for Q2=1, for Q2=2, for Q2=0.5 = Todd
- MC of TOF, MC of single rates, MC of e-p and π-n
- MC of whole experiment - from LH2+walls, p-to-n
- Proposed - table of expected results
- Technical - performance of SBS, HCAL, ECAL, TOF tests
- Collaboration tasks, preparation plan, MRI = Todd
- Summary - beam time request

Data trigger concept based on the following:

- NDET and VCAL with high thresholds
- TOF front layer as a proton tag on trigger level
- Electron/pion spectrometer tracker for off-line rejection of the ep and πn events

Single rates at the proposed 2.2 GeV, 100 uA on a 10-cm long (visible) target using DINREG calculations: at 30 degree (electron/pion arm) 75 msr of SBS:

III. INTRODUCTION

A. Motivation and Proposed Measurement

B. Proposal Outline

The text of the proposal is organized as follows:

- Section IV provides the physics background, motivation and formalism.
- Section V describes the experimental approach and equipment
- Section VI lays out the proposed measurement, expected rates, cross sections, triggers, etc.
- Section VII contains the results of simulation of the TOF, NDET, Veto spectrometer
- Section VIII we describe the data acquisition system.
- Section IX gives expected results, systematic and statistical uncertainties.
- Section X covers details of detectors, costs, etc.
- Section XI Conclusion.
- Section XII is LOI submitted to PAC 52

C. Proposed Naming Scheme

- Neutron Arm consists of sweeper magnet, TOF detector, NDET or NCAL or LND (neutron calorimeter)
- Veto Spectrometer consists of SBS magnet, GEMs and VCAL, which is the current SBS HCal that will be primarily used to detect electrons and pions
- The elastic reaction p($\vec{e}$, e'p) will be referred to as ep.
- The weak elastic reaction p($\vec{e}$, n)ν_e will be referred to as νn.
- The inelastic reaction p(γ, nπ^+) will be referred to as πn.

IV. PHYSICS MOTIVATION

A. Elastic Form Factors

The Sachs elastic electromagnetic form factors of the nucleon are well measured to $Q^2 \geq 10$ GeV^2. Below $Q^2 = 1$ GeV^2, all but the neutron electric form factor are well-described by the dipole form factor as shown in Figures 1 and 2 [4]. Ignoring relativistic effects, the Fourier transform of G_D gives a spatial dipole distribution for the electric charge and magnetization.

$$\frac{G_M^p(Q^2)}{\mu_p} = \frac{G_M^n(Q^2)}{\mu_n} = G_E^p(Q^2) = G_D(Q^2) \tag{1}$$

$$G_D(Q^2) := \frac{1}{\left(1 + Q^2/M_V^2\right)^2}, \tag{2}$$

where $M_V = 0.84$ GeV and Q^2 is measured in GeV^2.

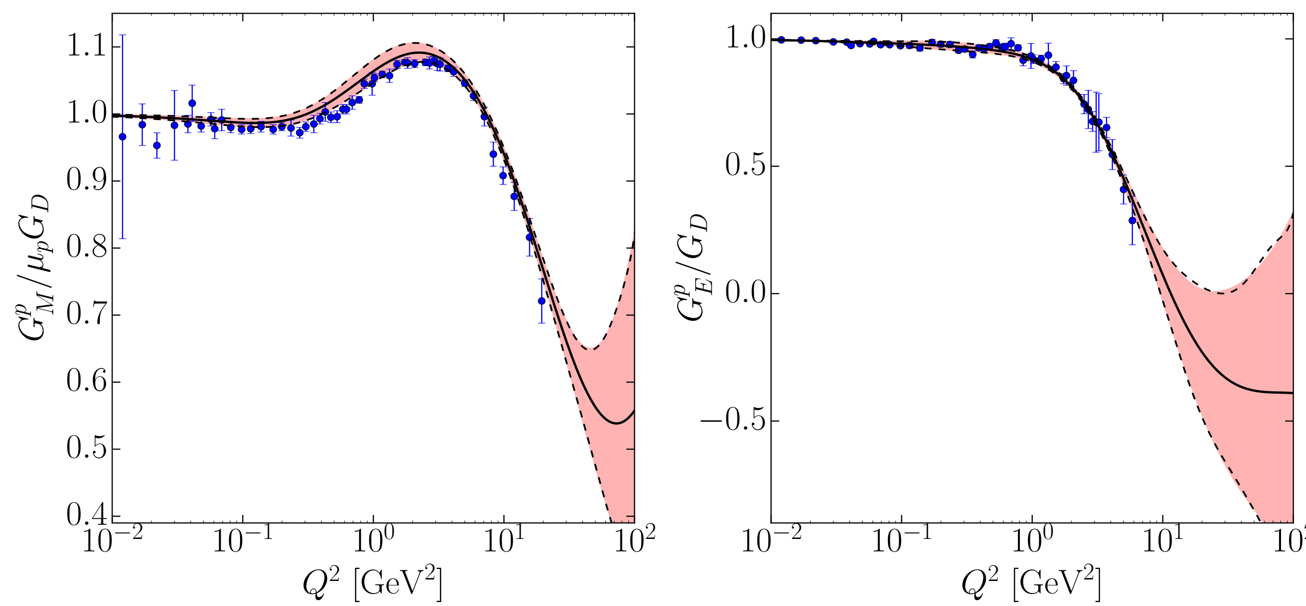

FIG. 1. This figure, taken from Ref. [4], shows a parameterization of world data for G_M^p/G_D (left) and G_E^p/G_D (right) shows dipole behavior below $Q^2 = 1$ GeV^2.

In contrast with the electromagnetic case, much less is know about the axial vector elastic form factor, $G_A(Q^2)$. All modern experiments have employed quasi-elastic scattering from a wide variety of nuclei where intriguing information from e.g. nucleon-nucleon correlations, resonant pion production and final state interactions, has been obtained. The MINERνA experiment, published in 2023 [5], was the first experiment since a 1980 bubble chamber experiment at BNL [6] to provide elastic scattering data from free protons ($\overline{\nu}_\mu$+p $\rightarrow$ μ^++ n), allowing one to probe the weak charge of the nucleon in the absence of nuclear effects.

B. Physics of the Weak Charged Current Interaction

For $Q^2 \sim 1$ GeV^2 it is typically assumed $G_A(Q^2)$ is also described by a dipole form factor as,

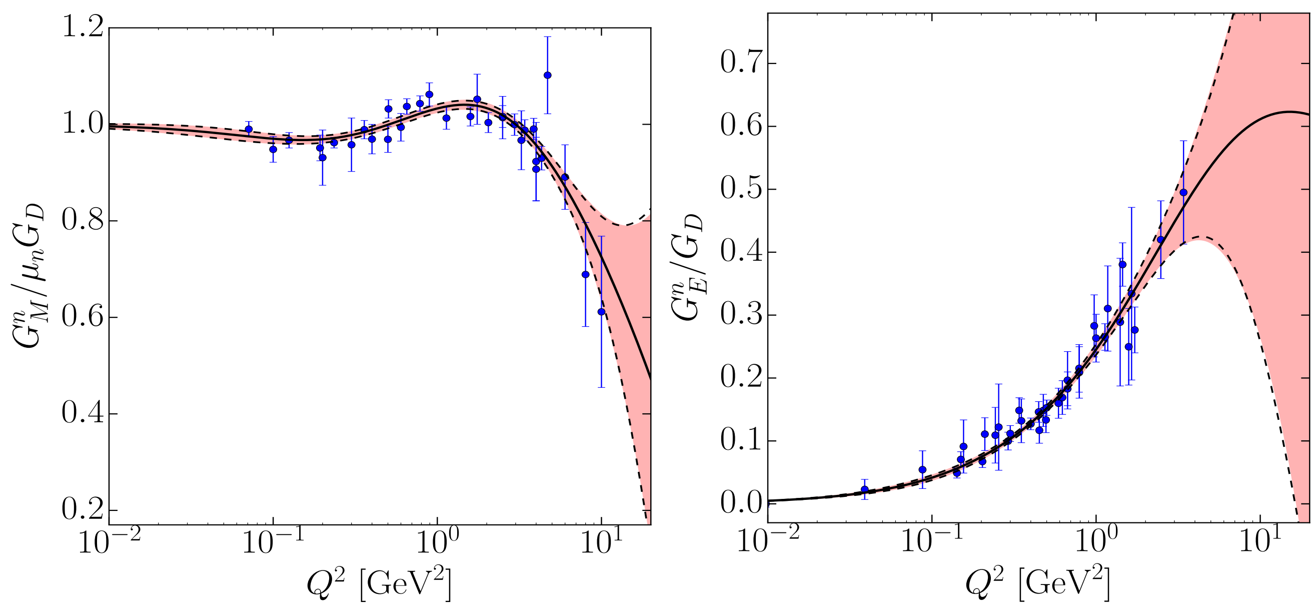

FIG. 2. This figure, taken from Ref. [4], shows a parameterization of world data for G_M^n/G_D (left) and G_E^n/G_D (right). Below $Q^2 = 1$ GeV^2, G_M^n shows dipole behavior while G_E^n does not.

$$G_A(Q^2) = \frac{\lambda}{\left(1 + Q^2/M_A^2\right)^2}, \tag{3}$$

where the $\lambda \equiv g_A/g_V = -1.2754 \pm 0.0013$ is obtained from neutron beta decay experiments [7].

- Recently, the MINERνA collaboration measured the reaction p($\overline{\nu}_\mu$, μ^+n) by scattering from free protons in a plastic scintillator target [1]. The measurement was not well-constrained kinematically due to the broad-spectrum neutrino beam with average $E_\nu = 5.4$ GeV. Also difficult is knowing the details of the neutrino flux (are these the same thing?). As such, the measurement covered a range in Q^2 approximately 0.1 - 5 GeV^2. By expanding G_A to first order in Q^2 about $Q^2 = 0$, they extracted an axial charge radius of 0.73 ± 0.17 fm. Cross section results are shown in Figure 3.

- More theoretical relevance: GPDs-Peter Kroll will provide. From the paper by M. Diehl and P. Kroll, arXiv:1302.4604 [hep-ph], the axial form factor is related to the GPDs by

$$G_A(t) = \int_0^1 dx \left[\tilde{H}_u^v(x,t) - \tilde{H}_d^v(x,t)\right] + 2\int_0^1 dx \left[\tilde{H}^{\overline{u}}(x,t) - \tilde{H}^{\overline{d}}(x,t)\right] \tag{4}$$

- LQCD The axial-vector and induced pseudoscalar form factors of the nucleon were calculated in lattice QCD by several groups. The paper by Gupta *et al.* [8] provides a nice formalism. In this paper they found, using the dipole ansatz, that the axial charge radius was 0.49(3) fm corresponding to $M_A = 1.39(9)$ GeV. Additional LQCD results are nicely summarized in Ref. [9]. Results are shown in Figures 4- **??**.

- Connection to neutrino experiments and discussion of how our result can fit in. Kordosky presentation from Minerva. Most useful to constrain neutrino energy spectrum and also having several data points would constrain G_A to aid w/ oscillation experiments. Finally, measurement

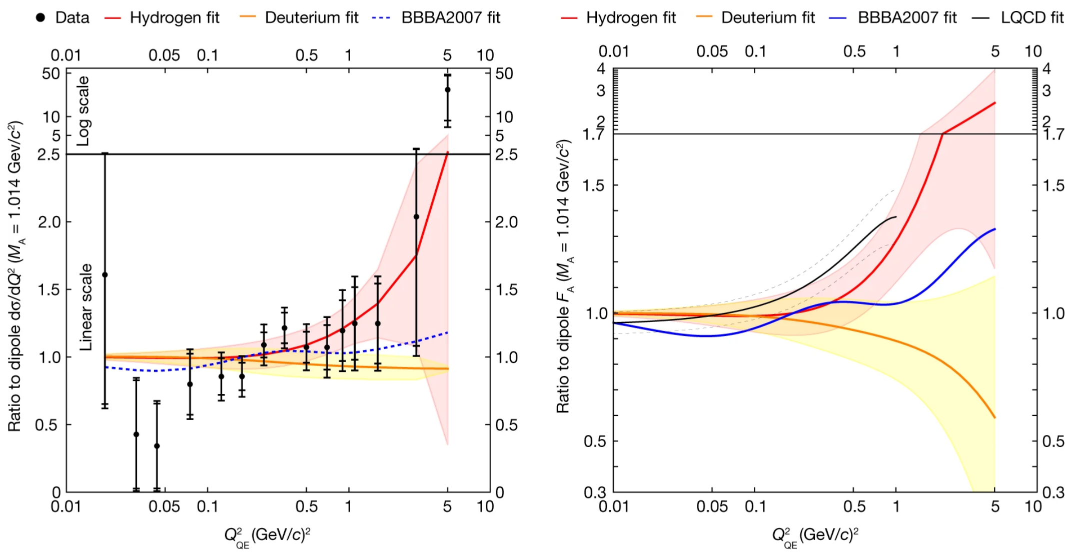

FIG. 3. Results from the recent MINERνA experiment [1]. Left, ratios of cross-sections to dipole cross-section with $M_A = 1.014$ GeV. The inner error bars on the data points account for 1 standard deviation due to statistical uncertainty only, and the full error bars include all sources of systematic uncertainties. Right, ratios to the dipole form factor. The hydrogen (this work) and deuterium F_A fits use the z expansion formalism; BBBA2007 uses a different empirical fit to deuterium and π-electroproduction data; whereas LQCD is a recent fit to lattice QCD calculations.

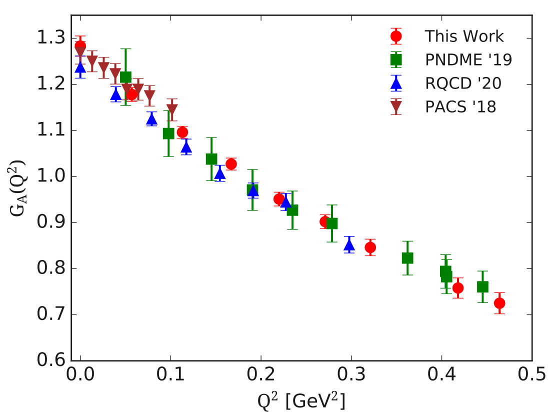

FIG. 4. $G_A(Q^2)$ from LQCD

of the pseudoscalar form factor is useful for tau neutrino oscillations due to the significantly larger $(m_\tau/M_N)^2$ term in the cross section. Cross section results from MINERνA are shown in Figure 3.

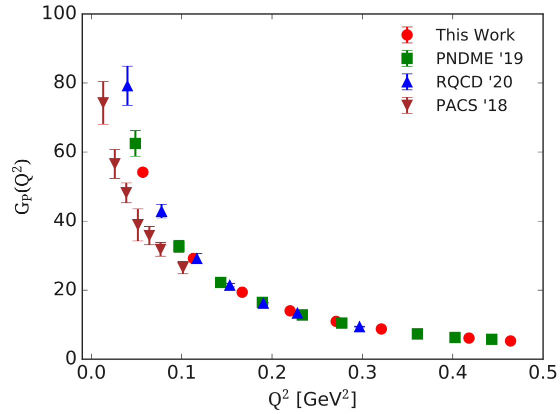

FIG. 5. $G_p(Q^2)$ from LQCD

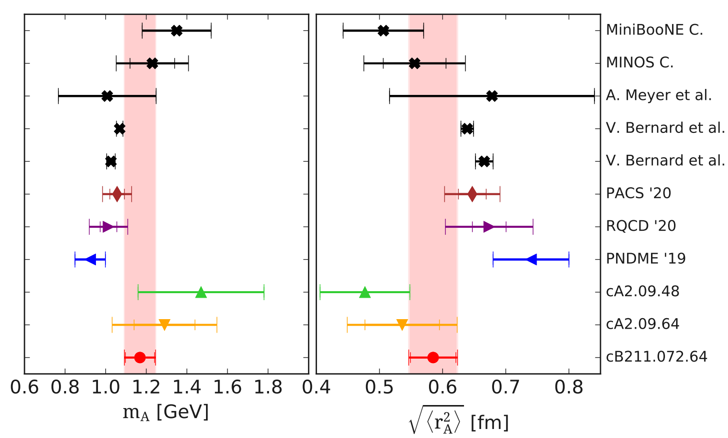

FIG. 6. M_A and r_A comparisons between LQCD and other measurements/calculations

C. Cross section and Formalism for the μn reaction

The process we will measure is p($\vec{e}$,n)ν at elastic scattering kinematics at $Q^2 = 1$ GeV^2. The interaction is mediated by the exchange of the weak W$^-$ boson. see Figure 7.

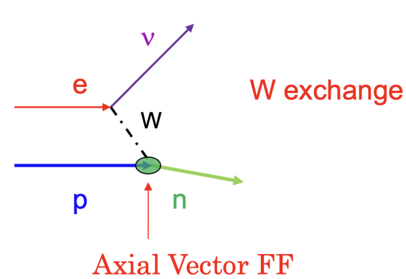

FIG. 7. The reaction studied in this experiment, p($\vec{e}$,n)ν, is shown here. The kinematics are elastic with the CC interaction is mediated by the exchange of a W$^-$ boson.

Note: Peter Kroll is currently working on the formalism for our reaction.

For the inverse reaction $\nu(k_1) + n(p_1) \to e^-(k_2) + p(p_2)$, the formalism is given below [10].

$$\left\langle p(p_2) \left| J^+_\lambda \right| n(p_1) \right\rangle = \cos\theta_c \, \overline{u}_p(p_2)\Gamma_\lambda u_n(p_1) \tag{5}$$

where

$$\Gamma_\lambda = \gamma_\lambda F^1_V(q^2) + \frac{i\sigma_{\lambda\nu}q^\nu \xi F^2_V(q^2)}{2M} + \gamma_\lambda\gamma_5 F_A(q^2) + \frac{q_\lambda\gamma_5 F_P(q^2)}{M} \tag{6}$$

where $\xi = \mu_p - \mu_n$, F_A is the axial vector form factor and F_P is the induced pseudoscalar form factor.

The formula for the cross section is:

$$\frac{d\sigma}{d|q^2|} = \frac{M^2 G^2 \cos^2\theta_c}{8\pi E^2_\nu} \left[A(q^2) - B(q^2)\frac{(s-u)}{M^2} + \frac{C(q^2)(s-u)^2}{M^4} \right] \tag{7}$$

where

$$(s-u) = 4ME_\nu + q + 2 - M^2 \tag{8}$$

and

$$A = \tau \left[4(1+\tau)|F_A|^2 - 4(1-\tau)|F^1_V|^2 + 4\tau(1-\tau)|\xi F^2_V|^2 + 16\tau Re\{F^{1*}_V \xi F^2_V\} - 4(1+\tau)|F_P|^2 \right] \tag{9}$$

$$B = 4\tau Re\{F^*_A(F^2_V + \xi F^2_V)\} \tag{10}$$

$$C = \frac{1}{4}\left(|F_A|^2 + |F^1_V|^2 + \tau|\xi F^2_V|^2 \right) \tag{11}$$

The isovector form factors can be expressed as follows

$$F^1_V(q^2) = [F^p_1(q^2) - F^n_1(q^2)] = \text{ Dirac electromagnetic isovector form factor.} \tag{12}$$

$$F^2_V(q^2) = \frac{\mu_p F^p_2(q^2) - \mu_n F^n_2(q^2)}{\mu_p - \mu_n} = \text{ Pauli electromagnetic isovector form factor.} \tag{13}$$

These may be written using the Sachs EM form factors using the relations TDA check these expressions

$$F^1_V(q^2) \;\; = \tfrac{1}{1+\tau}\left[(G^p_E + \tau G^p_M) - (G^n_E - \tau G^n_M) \right] \tag{14}$$

$$F^2_V(q^2) = \tfrac{1}{1+\tau}\left[\tfrac{1+\kappa_p}{\kappa_p}(G^p_M - G^p_E) - (G^n_M - G^n_E) \right] \tag{15}$$

then,

$$F^1_V(Q^2) = \frac{G^V_E(Q^2) + \tau G^V_M(Q^2)}{1+\tau} \tag{16}$$

$$F^2_V(Q^2) = \frac{G^V_M(Q^2) - G^V_E(Q^2)}{\xi(1+\tau)} \tag{17}$$

D. The νn Cross Section and Asymmetry

To estimate the the cross section for this process, we use the formalism above with parameterizations of the EM Sachs form factors from e.g. [4] and the axial dipole form factor with the current best value for $M_A =$.

Figures for Cross section versus theta, neutron energy,...

This reaction is 100% parity violating which means it has an asymmetry of 1. We will take data with longitudinally polarized beam, with rapid flipping of helicity states, and use the difference to isolate the νn reaction.

E. The ep Cross section and Asymmetry

The cross section for elastic p($\vec{e}$, e'p) is easily calculated for our kinematics using the standard Mott cross section with parameterizations of the elastic EM form factors. Figures needed include cross sections versus, E' and theta. Reaction kinematics.

This reaction has a parity violating asymmetry of xxx. By rejection of ep events we will reduce the contribution of this asymmetry to xxx.

F. Pion photoproduction

The reaction p(γ, π^+,n) can occur when real photons produced in the target interact with protons, and can also be produced through so-called quasi-real photons. Figures need cross sections. Asymmetry estimates?

V. EXPERIMENTAL SETUP

The setup includes: 20-cm-long LH_2 target with tungsten collimators limiting the target line of sight to 10 cm, neutron detector arm: sweeper magnet, TOF, NDET. Veto spectrometer: SBS, GEM, VCAL.

We expect to install the experiment in Hall C using a design proposed by Steve Lassiter to accommodate (approved) SBS experiments. The configuration will be similar to that shown in Figure 8.

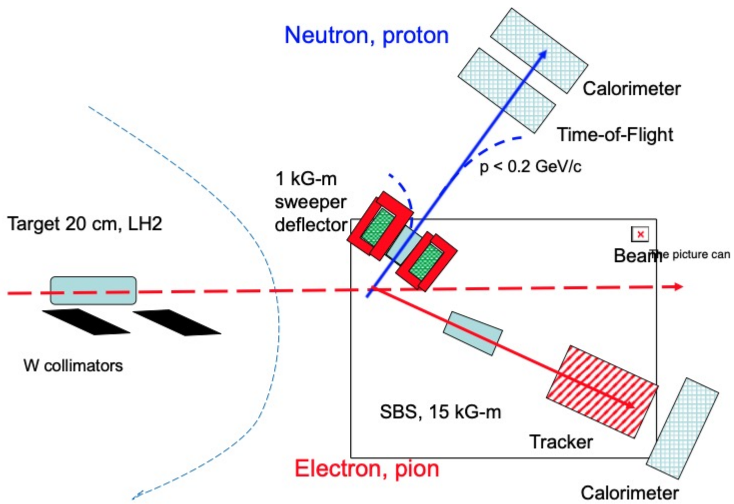

FIG. 8. Hall C design for SBS experiments.

Downstream of the target at a distance of 1.5 m we will place a dipole magnet (Bdl is 0.3 T-m) to spatially separate p/n (3-4 deg polar angle) at NDET and to sweep the low energy electrons and positrons.

A. The TOF detector

The Time of Flight detector consists of 7 horizontal and 140 vertical layers of 6 cm x 6 cm x 200 cm h x w x l scintillators with a PMT on each end. The geometry is based on the successful TOF detector in CLAS 12 []. It will be used to separate neutrons from the ν n reaction from those from the nπ reaction. For this to be successful requires timing resolution of 100 ps. The 2m length of the bars is chosen to match that of the successful CLAS12 TOF.

B. The NDET

The Width 1.8 m, height 8 m. This sets the kinematic range we can cover. The detector will be composed of 640 15 cm x 15 cm modules, similar to those used in the SBS HCAL detector. Each module will have 7 layers of iron + scintillator connected to a wavelength shifting plastic, connected through a light guide to a PMT.

C. The sweeper magnet

Vertical field to sweep low energy junk away and separate n from p events at the NDET.

D. Trigger logic

The trigger will come from a high threshold hit in the NDET. This can be a proton or neutron.

E. SBS Veto Spectrometer

The front face of the SBS magnet is located 1.6 m from the target center. The height and depth of the poles is 122 cm x 122 cm. The gap between the poles, horizontal is 46 cm. Specifications for the SBS spectrometer are shown in Figure 9.

Parameters of SBS

Solid angle

$\theta_{central}$, degree	Ω, msr	D, meter	Hor. range, degree	Vert. range, degree
3.5	5	9.5	$\pm$ 1.3	$\pm$3.3
5.0	12	5.8	$\pm$ 1.9	$\pm$4.9
7.5	30	3.2	$\pm$ 3	$\pm$8
15	72	1.6	$\pm$ 4.8	$\pm$12.2
30	76	1.5	$\pm$ 4.9	$\pm$12.5

Resolution:

Momentum => $\frac{\sigma_p}{P} = \mathbf{0.0029} + \mathbf{0.0003} \times \boldsymbol{p}[\mathrm{GeV}]$

Angular => $\sigma_\theta = \mathbf{0.14} + \mathbf{1.3}/\boldsymbol{p}$ [GeV], mrad

Momentum acceptance => $\boldsymbol{P}$ range from $\mathbf{2} - \mathbf{10}$, GeV/c

FIG. 9. Specifications for the SBS spectrometer from the SBS G_E^p experiment.

F. GEMS

The GEM detectors for the veto spectrometer will be re-used from the SBS G=G_E^p experiment as shown in Figure 10

G. VCAL

The SBS hadron calorimeter (HCAL) was used in the first group of SBS experiments to detect recoil protons and neutrons in quasi-elastic scattering from deuterium and ^{3}He. It will be repurposed, as VCAL, for detecting electrons and pions coincident with neutrons and protons in the neutron arm. It consists of 288 modules, each containing alternating layers of iron and scintillator. Light from the scintillators is transported by wavelength shifting plastic sheet to a light guide into a single

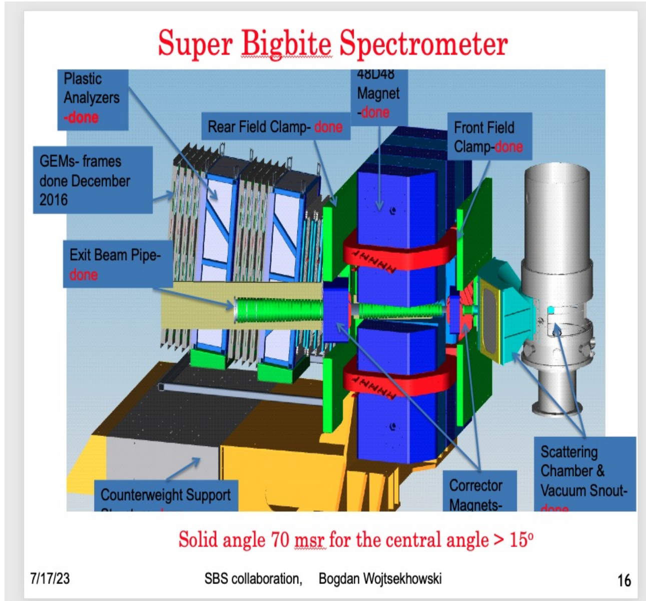

FIG. 10. This figure shows the SBS magnet and GEM tracking planes that will be used, along with the existing HCAL detector to reject e.g. elastic ep, pion production, and DIS events

PMT. See Figure 11. Each module is 15 cm x 15 cm and are arranged in 12 columns and 24 rows, see Figure 12.

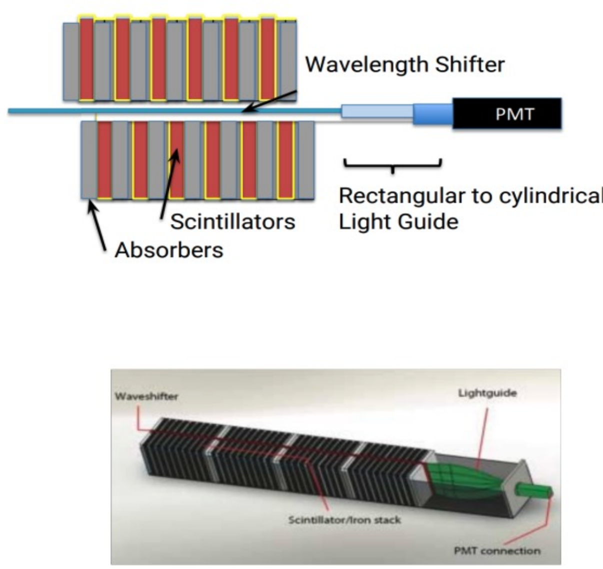

FIG. 11. Each HCAL module is made of alternating layers of iron and scintillator, with light transported by wavelength shifting plastic, through light guides and into a photomultiplier tube. Modules are 15 cm x 15 cm.

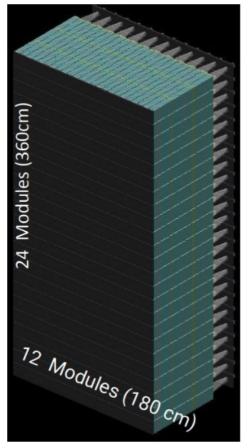

FIG. 12. The HCAL detector consists of 12 columns and 24 rows of iron/scintillator modules. The size of the detector is 180 cm x 360 cm, W x H

VI. PROPOSED MEASUREMENTS

An electron beam with a current of 100 μA at an energy of 2.2 GeV will be used with a 20-cm-long (or 10 cm?) target of liquid hydrogen.
Neutrons from the weak scattering process will be detected in the TOF+NDET
Background will be vetoed by SBS/GEM/HCAL. Time requested will be 500 hours.

A. Cross sections

The p($\vec{e}$,n)ν cross section is estimated to be 10^{-39} cm^2/sr. The pion photo-production cross section is $\sim 10^8$ larger and the e-p elastic $\sim 10^7$ larger at $Q^2 = 1$ GeV^2.

B. Detection of reactions

- Weak elastic scattering. The trigger will be generated by energy deposition above ?? MeV threshold in the NDET. The TOF will be used to separate protons from neutrons using the assumption that neutrons will not produce a signal in the first 1-2 layers of the TOF. Protons will also be physically separated from neutrons by the sweeper magnet. Identification of real events in the TOF + NDET will be done by TOF measurement which must be accomplished at the 100 ps level.
- Elastic e-p scattering events will be rejected by the detection of a coincident electron in the SBS detector.
- Correlated π^- + n events will be rejected by pion detection in the SBS detector.

The electron beam will be longitudinally polarized and helicity will be flipped. Because the νn process is 100% parity violating. The ep scattering will also have a PV asymmetry. The critical item is to sufficiently reject the ep events to as to isolate the νn signal. It is expected we can achieve a rejection factor of 10k which will give a 30% accuracy for the cross section and 15% for the axial vector form factor.

Here are some estimates of rates and asymmetries from BW.

- Total events in 500h is 3.4×10^{11}, primarily from ep elastic events.
- Total νn events in 500 h is 2.7×10^4.
- The ep elastic asymmetry is 5×10^{-5}. The νn asymmetry is 1.
- With a rejection factor of 10^4, the number of accepted ep events is 3.4×10^7.
- This gives a total asymmetry of $\sim 8 \times 10^{-4}$ with uncertainty xxx
- Question, I thought the πn events were contributing 10x more rate than the ep events. What happens to these? What is the πn asymmetry?

C. Calibration, efficiencies and systematics

D. Calculation of the experiment sensitivity

VII. MONTE CARLO SIMULATION

The expected background rates, the strategy of data analysis and the expected search accuracy were analysed using the Monte Carlo simulation of the proposed experimental set up.

A. Geant4-based simulation

GEANT 4 simulation of the neutron arm is underway by Weizhi Xiong and Yi Li from Shandong University, Qingdao. Below are shown their first results Shown in Figure 13 is first virtual plane located at the front of a 0.5 T sweeper magnet located 1.5 m from the target. The second virtual detector is located in front of the TOF detector. Figure 14 shows the particle rate versus energy at virtual plans 1 and 2. The spectrum at plane 1 is dominated by photons, electrons and positrons below 10 MeV produced in the target. These low energy (charged) particles will be swept out of the detector acceptance by the sweeper magnet. The spectrum of particles below 10 MeV is reduced by a factor of 10^3 at the second virtual plane though it is believed many of these particles are created by reactions in the air between the sweeper magnet and TOF.

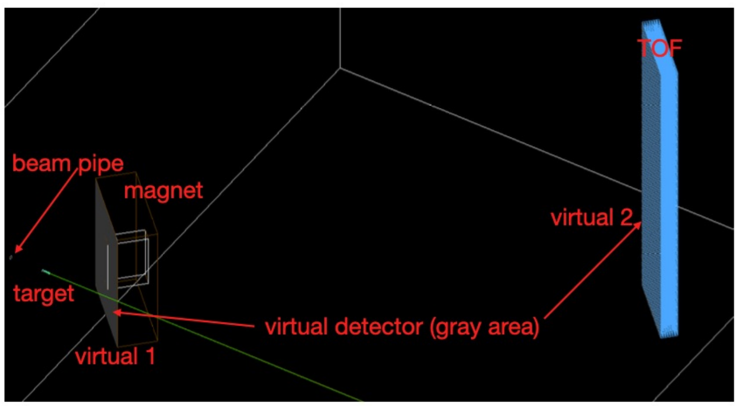

FIG. 13. Geometry for TOF and NDET used in simulation. The first virtual plane is at the front of a 0.5 T sweeper magnet located 1.5 m from the target. The second virtual detector is located in front of the TOF detector.

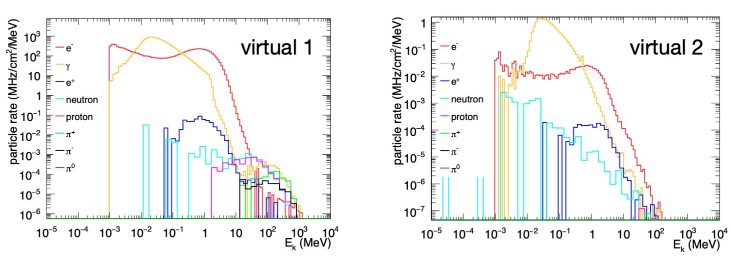

FIG. 14. Geometry for TOF and NDET used in simulation. The first virtual plane is at the front of a 0.5 T sweeper magnet located 1.5 m from the target. The second virtual detector is located in front of the TOF detector.

VIII. DAQ SYSTEM

- The TOF timing signals will be measured using CAEN V775 (or VETROC Camsonne). 32 channels, 35 ps timing resolution.
- ADC spectra from TOF will be read by FADC
- GEMs and HCal use existing DAQ
- DAQ for NDET?

IX. EXPECTED RESULTS AND BEAM TIME REQUEST

A. Expected Results

A The total request for this proposal is 50 days.

Kin. #	Beam energy, GeV	Beam, μA		Time, days
C1	2.2	100 $\vec{e}^-$	50	
	Total requested time			50

TABLE I. The beam time request for the AVFF experiment.

X. TECHNICAL CONSIDERATIONS AND NEEDS

A. Timeline

What drives the timeline of this experiment?

- Simulation of neutron - has begun
- Simulation of background - has begun?
- Prototype of TOF - has barely begun, 4 scintillator bars and 8 PMTs purchased
- prototype of NDET - copy HCAL modules?
- Prototype of TOF/NDET DAQ
- Design of TOF/NDET system
- Specify and purchase sweeper magnet
- Purchase DAQ for neutron arm
- Modifications of SBS/GEM/HCAL veto system
- Construction of NDET
- Construction of TOF
- Construction of DAQ

Anticipated costs > \$10 M

- TOF scintillators 980 x \$1.5k/ea = \$1.5 M
- PMTs: \$1.5 M
- Front end CF discriminators 980 channels
- NDET
- Sweeper magnet and supply
- FADCs TOF + NDET?
- 25 ps VETROC TDCs TOF + NDET?

Preparation of proposal needed now,

- Simulation of experiment
- Simulation of backgrounds
- Calculation of cross sections and rates
- Study of trigger/DAQ rates
- Study of veto efficiency
- Physics motivation
- Cost estimate

Upon approval of experiment, immediate manpower needed for

- Full simulation
- Prototype of TOF including DAQ
- Prototype of NDET including DAQ

Followed by

- Jefferson Lab design group - TOF, NDET, sweeper, veto spectrometer design
- TOF construction - MRI
- NDET construction - MRI
- DAQ(s) - MRI
- Simulation/studies for $Q^2 = 0.5$ and $2.0\ \mathrm{GeV}^2$

XI. CONCLUSION

We request 500 hours of total time to do a measurement of the proton axial-vector form factor at $Q^2 = 1$ (GeV/c)^2.

This experiment will take place in Hall ?, utilizing a 100 μA, 2.2 GeV electron beam with high longitudinal polarization. Neutrons, and protons from e-p elastic scattering, will be detected using a TOF plus hadron calorimeter preceded by a sweeper magnet to eliminate low energy charged particle background and to improve separation of n and p events. A veto arm detector designed to the two largest background processes, e-p elastic electromagnetic scattering and pion photo-production. This veto detector consists of the existing SBS magnet and GEM tracking system plus the SBS HCal detector for e/π separation.

XII. PAC52 REVIEW OF LOI

LOI12-24-009

Title: Measurement of the Nucleon Axial Vector Form Factor at $Q^2 = 1$ (GeV/c)^2

Spokespersons: B. Wojtsekhowski (contact)

Motivation: This LOI proposes to measure the axial-vector form factor of the nucleon using the reaction $H(e^-, n)\nu_e$. Most of the existing experimental measurements of this form factor come from neutrino scattering experiments with wide-band beams and often with nuclear targets. In contrast, the uniqueness of the proposed measurement is that it will use a mono-chromatic (known) beam and a nucleon target. Knowledge of the axial-vector form factor is becoming increasingly important for precision accelerator-based neutrino oscillation experiments, especially for those that compare neutrinos and antineutrinos.

Measurement and Feasibility: The request is for 25 days of electron data-taking at 2.2 GeV on a liquid hydrogen target in Hall C. For the detector, the proposal is to use the electron/pion arm from the existing SBS magnet, the SBS GEM chambers, and the lead-glass electromagnetic calorimeter that is currently under construction for the Gep experiment E12-07-109, which will run in 2025. The rest of the experimental needs will require new investment.

Given that the neutrino signal being probed is ~7-8 orders of magnitude smaller than the elastic electron scattering and pion photo-production reactions, the proposed measurement requires significant strategies for background rejection (~ x 10^4 rejection for the e-p process). While the precision of the measurement will depend strongly on the success of such background rejection, even an initial measurement of $G_A(Q^2)$ at twice the quoted precision would be valuable, given the dearth of existing experimental data.

Issues: The LOI is short on detail and lacking in physics plots. Overall, the proposal needs a more detailed description of the measurement itself, the associated theory, and the detector setup that will be used. A full simulation and description detailing the strategy for background rejection will be critical content for a full proposal. A plot of the planned accuracy of the axial-form factor measurement compared to existing measurements should be produced. It will also be important to tabulate to what extent existing vs. new experimental equipment will be required to carry out the planned measurement.

Summary: This LOI offers a unique opportunity to measure the axial-vector form factor (the least well-known nucleon form factor) in a very different manner than is commonly probed in neutrino scattering. Such a measurement is of considerable importance for accelerator-based neutrino oscillation experiments. The PAC encourages the proponents to proceed to a full proposal after the above issues are addressed. The PAC encourages the use of a full Monte Carlo simulation to assess detector performance, background levels, and systematic uncertainties. If this method of extracting the axial-vector form factor proves successful, the PAC notes that this could become part of a larger measurement campaign. In particular, a measurement of the Q^2 dependence of the axial-vector form factor would be of great interest to the neutrino scattering community.

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