The Nucleon Axial Form Factor

A potential new experiment for the SBS

Jim Napolitano, SBS Collaboration Meeting, 12-13 September 2024

Reminder: Elastic Form Factors

Vector Interaction

$$\langle p+q\,|\,J_V^\mu\,|\,p\rangle = \bar{u}(p+q)\left[F_1(q^2)\gamma^\mu + \frac{\kappa}{2m}F_2(q^2)i\sigma^{\mu\nu}q_\nu\right]u(p)$$

Reduce to charge and magnetic moment at zero momentum transfer.

Well understood: Measured using elastic electron scattering

Axial-Vector Interaction

$$\langle p+q\,|\,J_A^\mu\,|\,p\rangle = \bar{u}(p+q)\left[G_1(q^2)\gamma^\mu\gamma^5 + G_3(q^2)q^\mu\gamma^5\right]u(p)$$

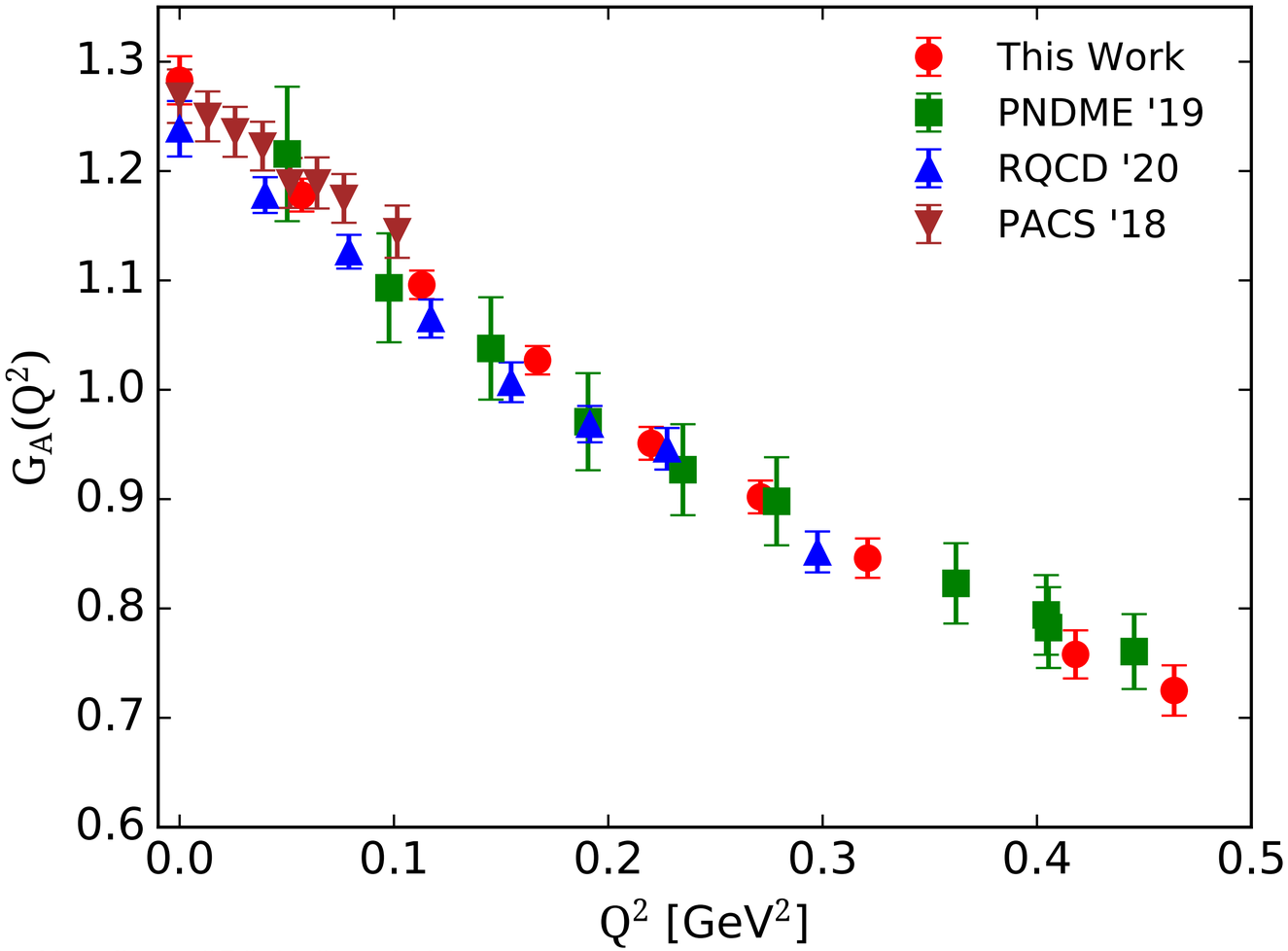
Well understood at zero momentum transfer (beta decay)

How to measure at finite momentum transfer?

- Cheat: Use pion production to add the γ^5
- Use reactions with neutrinos

These Form Factors are being Calculated

Example: C. Alexandrou, et al., PRD 103 (2021) 034509



"Nucleon axial and pseudoscalar form factors from lattice QCD at the physical point"

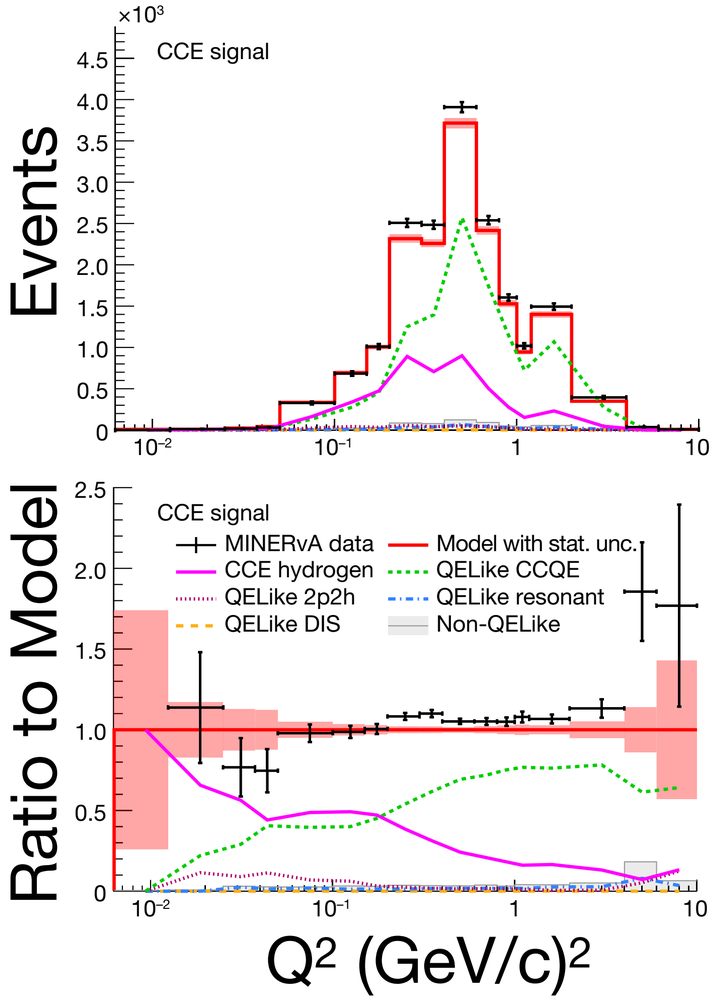
Note that they get the correct value at zero momentum transfer.

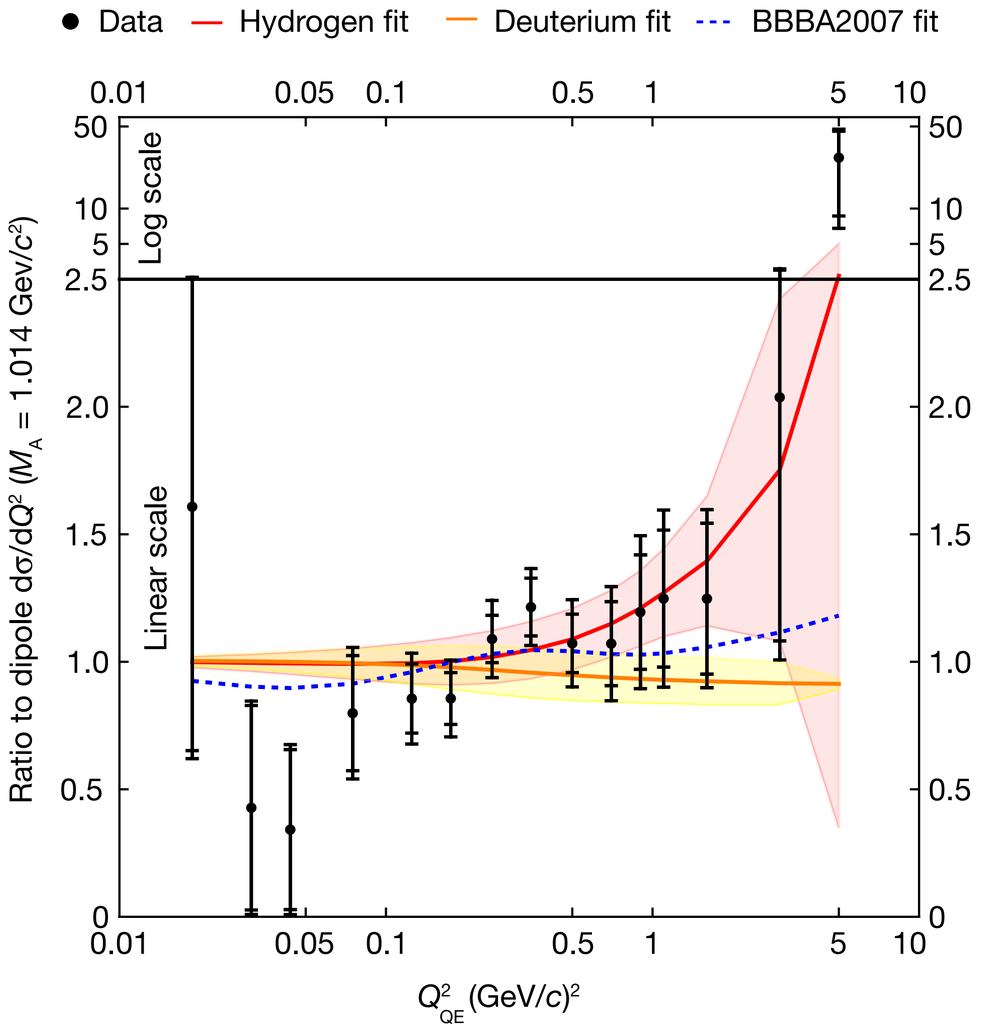
Useful benchmark for testing precision LQCD calculations

See also A Meyer, A Walker-Loud, C Wilkinson, Annu. Rev. Nucl. Part. Sci. 2022. 72:205–32

Example with Neutrino Beams

T. Cai, et al. (MINERvA), Nature 614 (2023) 48





- $\bar{\nu}_\mu p \rightarrow \mu^+(n)$
- Plastic scintillator target
- Fold in the calculated neutrino spectrum

Another possibility is $\nu_\mu n \rightarrow \mu^- p$ but now the nucleon target is bound up in a nucleus, and the form factor is "renormalized".

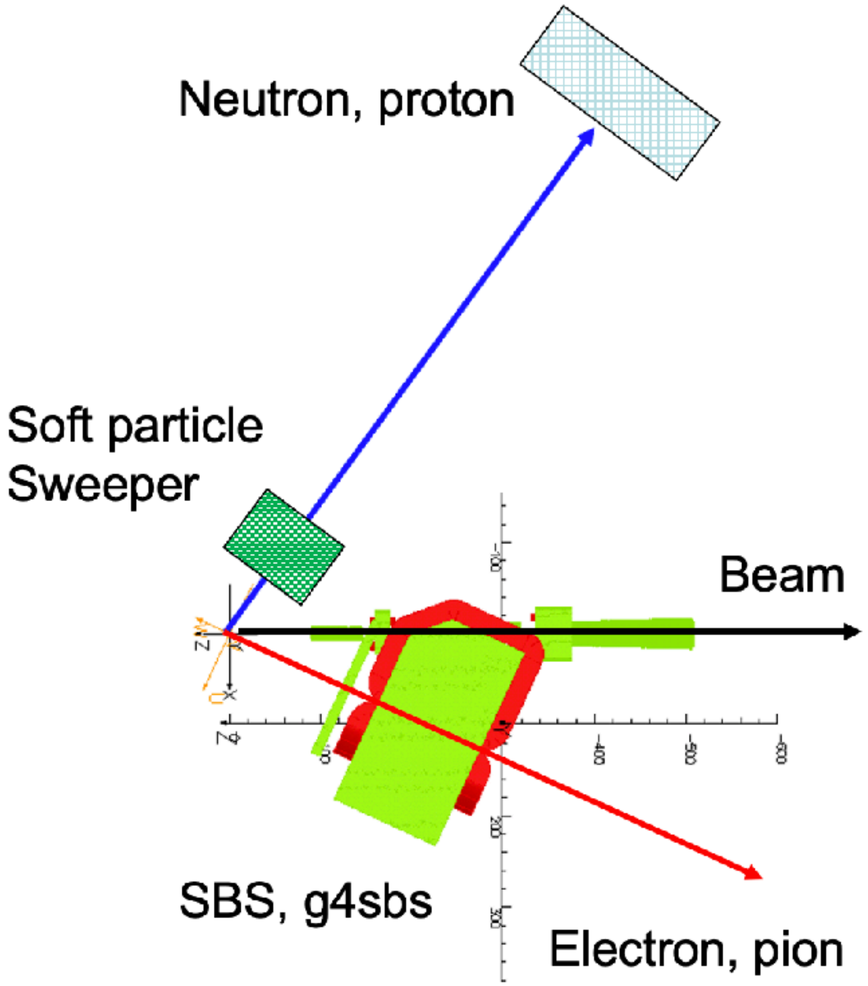
The Opportunity for CEBAF and SBS

A Fully Constrained Kinematic Measurement

$$e^- p \rightarrow \nu_e n$$

- Precision electron beam on a liquid hydrogen target
- Detect the neutron: Energy and Time-of-Flight versus angle
- Suppress backgrounds: There are ≈six orders of magnitude to deal with, especially pion and electron backgrounds
- Key: The reaction only proceeds for left handed electrons

Letter of Intent to PAC 52 (Summer 2024)

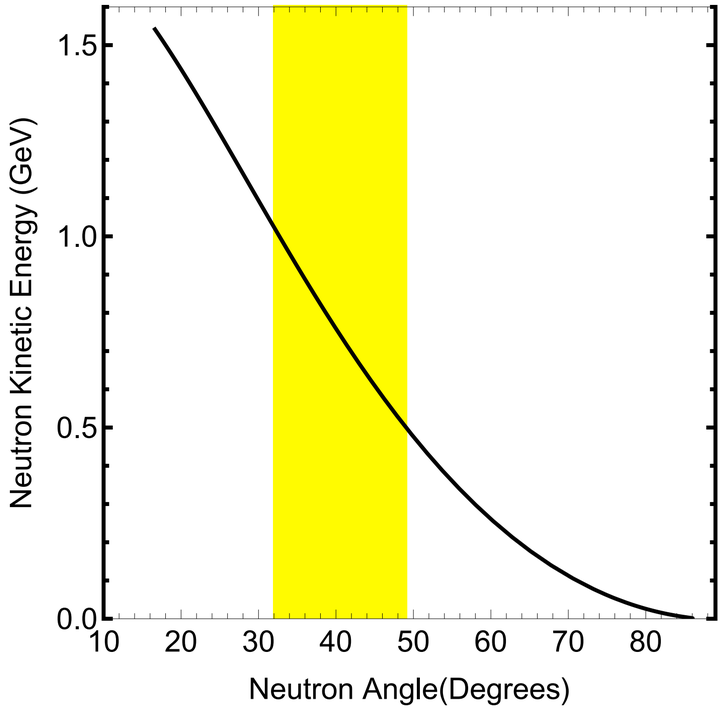


Key Assumptions

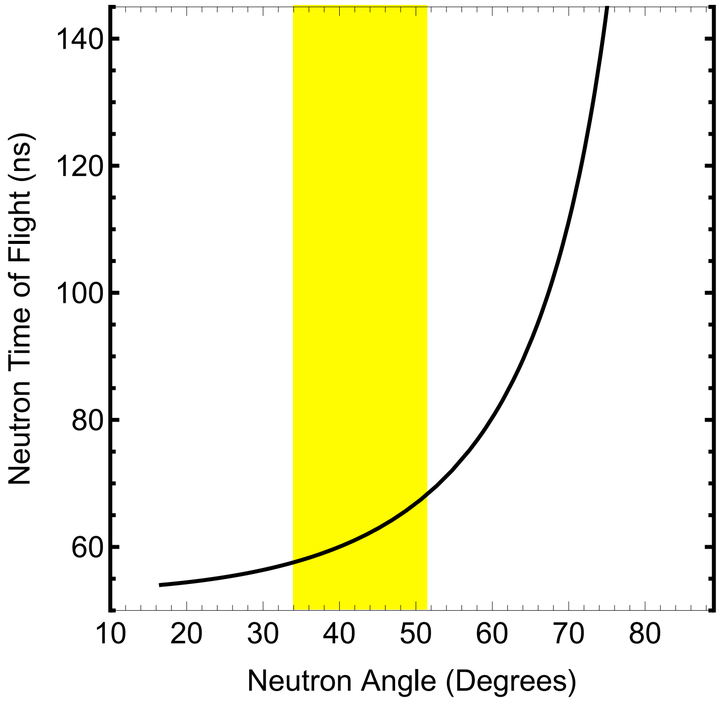
- A 500-hour data taking run with a beam on a 10-cm-long LH2 target in Hall C.
- A 100 μA electron beam at 2.2 GeV energy with a high degree of circular polarization.
- A large acceptance magnetic spectrometer to veto events from the processes with the final state electron or pion.
- A large size high efficiency neutron detector with time resolution better than 100 ps at a distance of 15 m from the target (75 msr).
- A magnet covering the neutron arm acceptance to sweep out charged particles.

Kinematic Coverage versus Neutron Angle

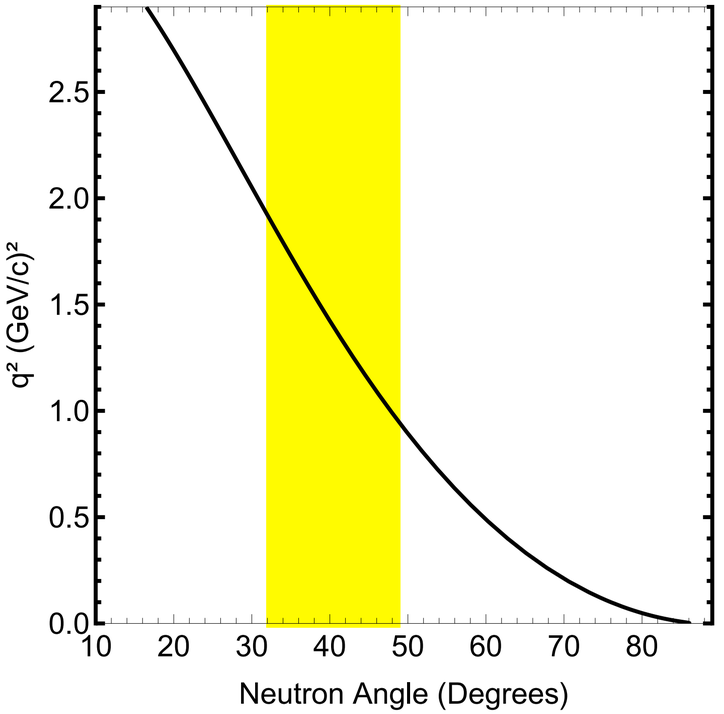
Kinetic Energy



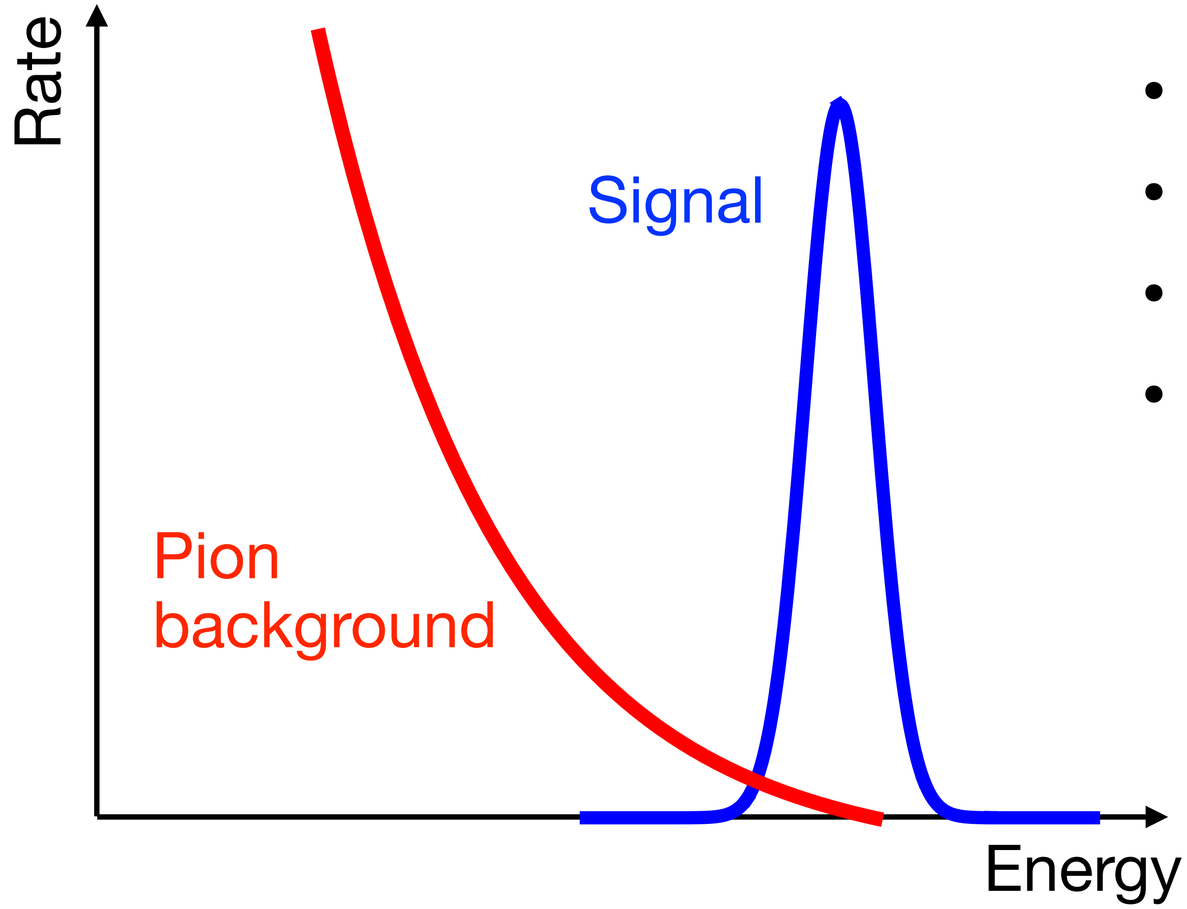
Time of Flight



Momentum Transfer



Rates and Backgrounds



- θ_n=30°, $\Delta\Omega_n$=75msr, 15m from target
- Assume 100ps neutron TOF resolution
- Rate (signal) ≈ 23 per hour
- Rate (Pion background) ≈ 40K per hour
- Rate (ep Elastic) ≈ 4K per hour (tricks!)

Final background subtraction done by flipping the electron polarization.

☞ Expected result on signal cross section is $(1.1\pm0.3)\times10^{-39}$ cm^2/sr

Comments from PAC 52

Issues: 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.

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.

Next Steps

Inaugural collaboration meeting tomorrow (Sat 14 September)

- Strengthen background calculations for pion photo-production and elastic electron scattering
- Design and prototype neutron detector for good position, energy, and time resolution
- Produce a full Monte Carlo simulation of all components and background sources
- Make formal proposal to PAC 53