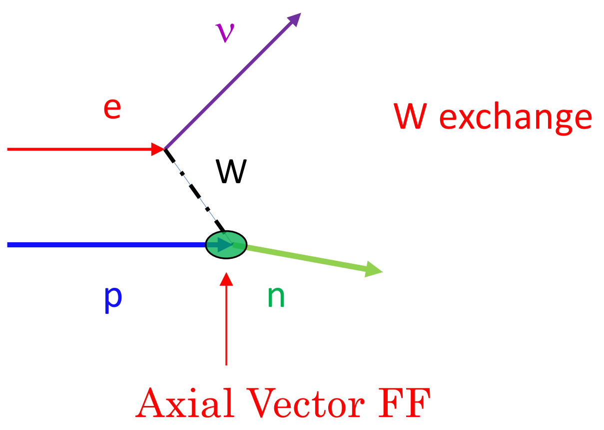
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Weak Axial Vector Form Factor



Beta decay has played a crucial role in the history *of particle physics* (neutrino hypothesis, parity violation, V-A theory, …)

Neutrino oscillation is of great theoretical and experimental interest, as the precise properties of the process can shed light on several properties of the neutrino. In particular, it implies that the neutrino has a non-zero mass, which requires a modification to the Standard Model of particle physics.

Challenges in the study of $e + p \dashrightarrow \nu + n$ process

- Cross section for the weak process is ~ 10^{-39} cm^2/sr
- Pion photo-production cross section ~ 10^8 of the weak one
- Proton rate from electron elastic e-p ~ 10^7 of the weak one

Proposal was submitted to PAC53: PR12-25-009

The Nucleon Axial-Vector Form Factor from the $p(\vec{e}, n)\nu_e$ Reaction

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II. ABSTRACT

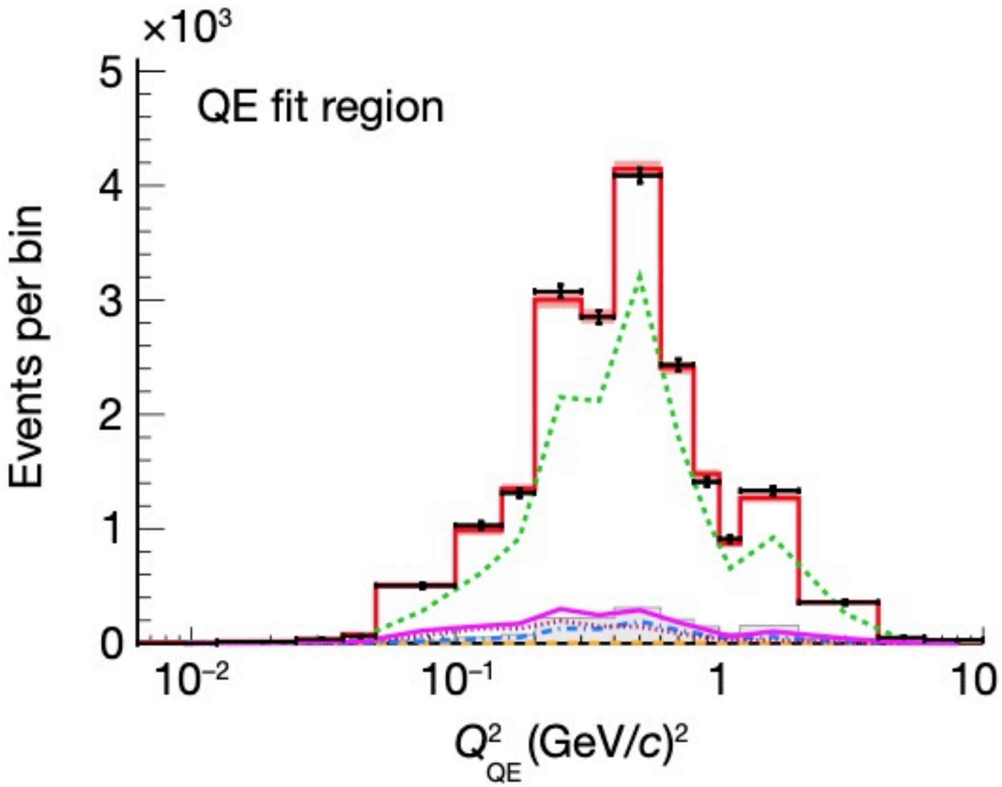
The nucleon Axial-Vector Form Factor has been an important part of hadron physics since the 1960s [9] and a number of pion electro-production experiments were made [10, 11] with the goal of extracting F_A even with significant model dependence. Neutrino scattering experiments from hydrogen and deuterium bubble chambers [12] have also been performed, but the results for F_A had low accuracy due to limited statistics. A recent result from MINERνA [5] improved the accuracy of F_A significantly, and comparison with a direct study of the $p(\vec{e}, n)\nu_e$ reaction, which we are proposing, will be useful.

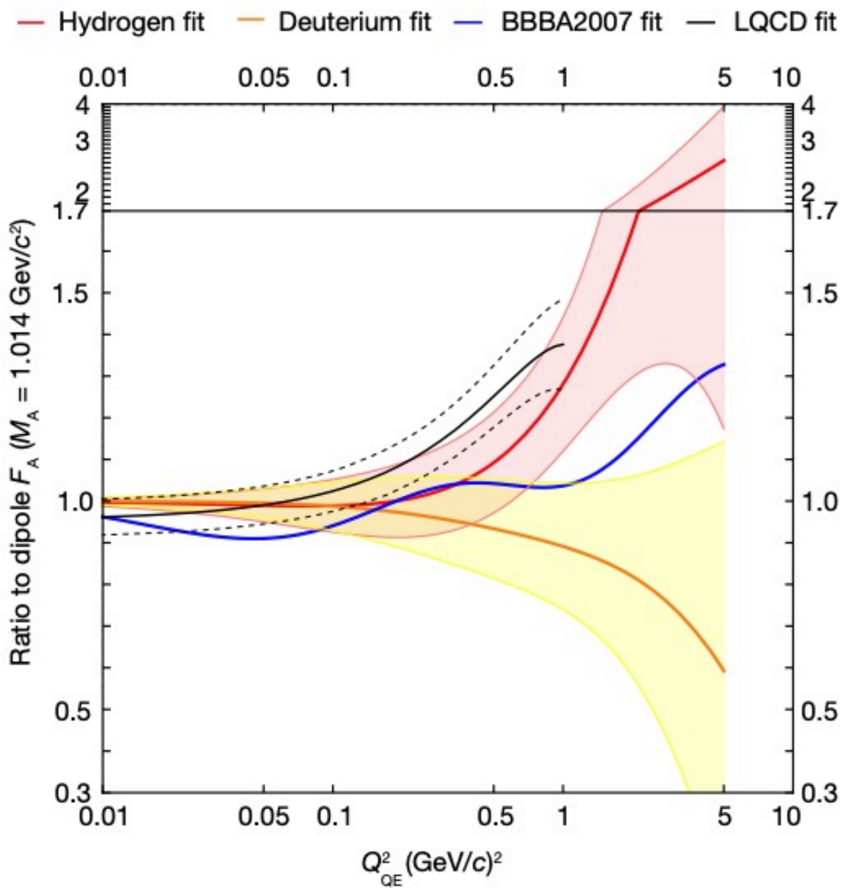
The experiment will use a polarized electron beam and a liquid hydrogen target. We will detect outgoing neutrons from the charged current (CC) reaction p($\vec{e}$,n)ν in a neutron arm consisting of time-of-flight detectors and a hadron calorimeter, which will allow us to determine the axial vector form factor of the nucleon at $Q^2 = 1$ (GeV/c)^2. Neutrons from this reaction must be separated from two large backgrounds: 1) protons from e-p elastic EM scattering and 2) neutrons from pion photo-production. Most of the elastic protons will be swept off the acceptance of the neutron detector using a 1 Tesla-meter magnet. Neutrons from pion photo-production will be eliminated using geometric and timing information from the neutron detector to precisely reconstruct the energy of the incident electron. A time resolution of 100 ps is required.

The experiment will take advantage of the high longitudinal polarization of the electron beam and 100% physics asymmetry of the CC reaction to obtain the final number of desirable neutrons. The electron beam will have energy of 2.2 GeV and current of 120 μA for production running. Calibration of the neutron calorimeter using e-p events and rejection of backgrounds in production running will be done using a "veto" spectrometer consisting of the GEMS and HCAL.

The expected result for the Axial-Vector Form Factor will have 39% relative accuracy. Assuming a dipole form factor, the relative accuracy for M_A from the proposed data point will be 20%.

Minerva data and results for F_A





Luminosity and statistics

L_{ep}= 3.2 x 10^{38} for 10 cm LH2 x 120 μA

Photon flux estimate:

Quasi real: I_e x 0.013 x dE_γ/E_e x 0.75 (Budnev-1975)

Real: I_e x 0.017 x dE_γ/E_e (25cm LH2 / 2 / 735cm)

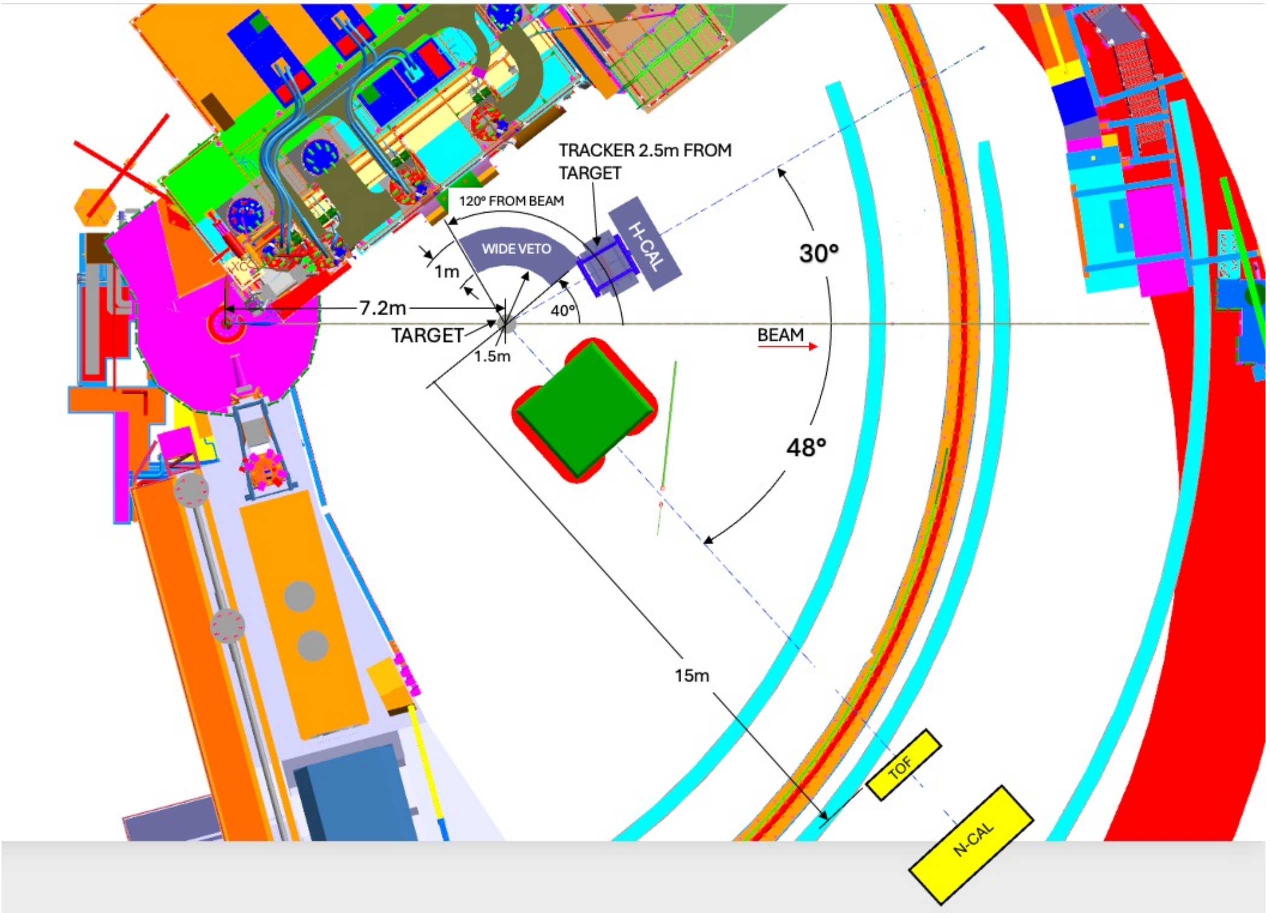
I_e x (0.013 x 0.014 x 0.75 + 0.017x 0.014)

$L_{\gamma p}$= 1.9 x 10^{35}

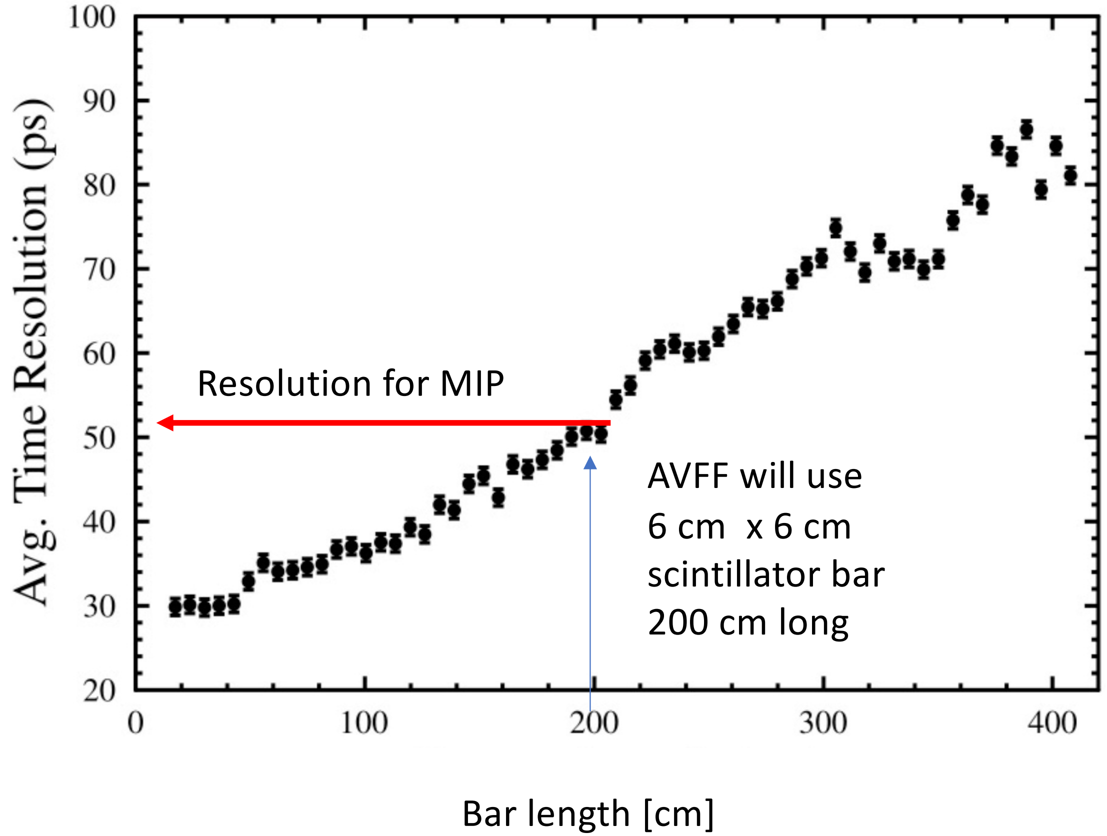
CC process	**Event Rate (Hz)**	**Total events**
$p(\vec{e},n)\nu_e$	0.0022	9.64k
Background processes	**Event rate (Hz)**	**Total events**
e-p on hydrogen	0.005	22k
e-n on Al windows	0.055	238k
π^+-n hydrogen	0.193	832k
π^+-n rescattering	0.01	43k
π^+-n on Al windows	0.04	173k
p-n on Al windows	0.003	11k
Combined Background	**0.305**	**1320k**

Addition background 2-pion related => 10x more

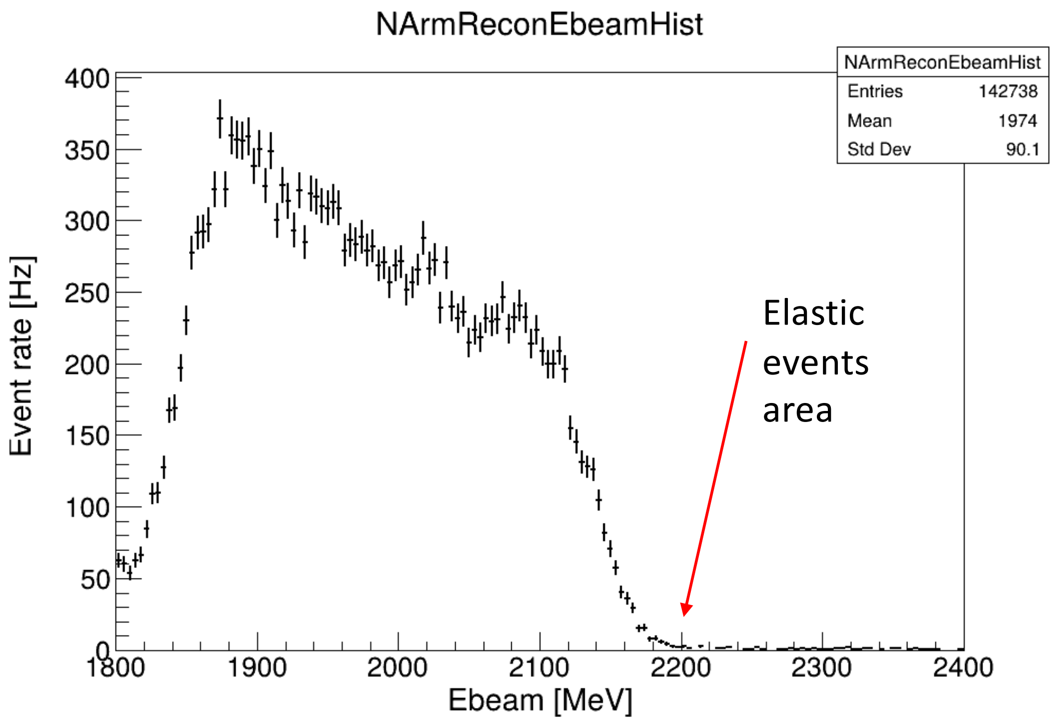
Experiment layout in Hall C



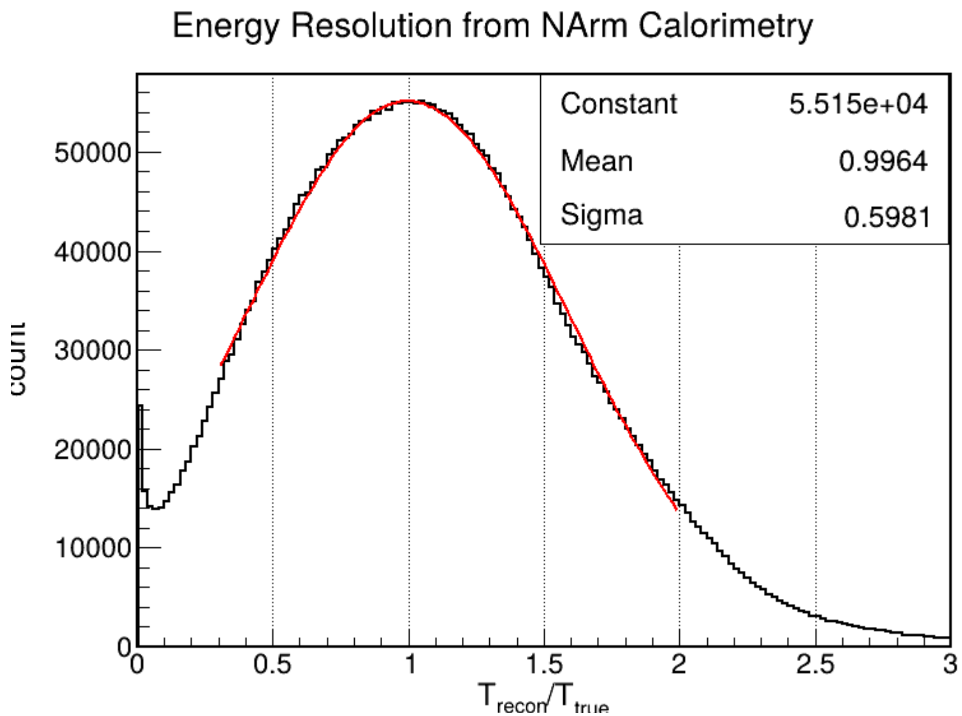
Pico-second time resolution from CLAS12



Reconstructed beam energy (eq. missing mass)



Hadron calorimeter (SBS)



Cross section measurement with polarized beam

$$\frac{d\sigma}{d\Omega} = \frac{(N_+ - N_-)/\eta_n}{P_b \times IL \times \Delta\Omega},$$

$$R = (N_+ - N_-)/(N_+ + N_-),$$

$$\frac{\Delta\sigma}{\sigma} = \frac{1}{\sqrt{N_+ + N_-} \times R} = \frac{\sqrt{N_+ + N_-}}{N_+ - N_-},$$

Proposal summary

	Target	Beam energy, GeV	Beam, μA	Time, days
Calibration	LH2/LD2	2.2	1	2.5
Production	LH2	2.2	120	50
Beam polarization	Moller	2.2	1	2.5
Total requested time				55

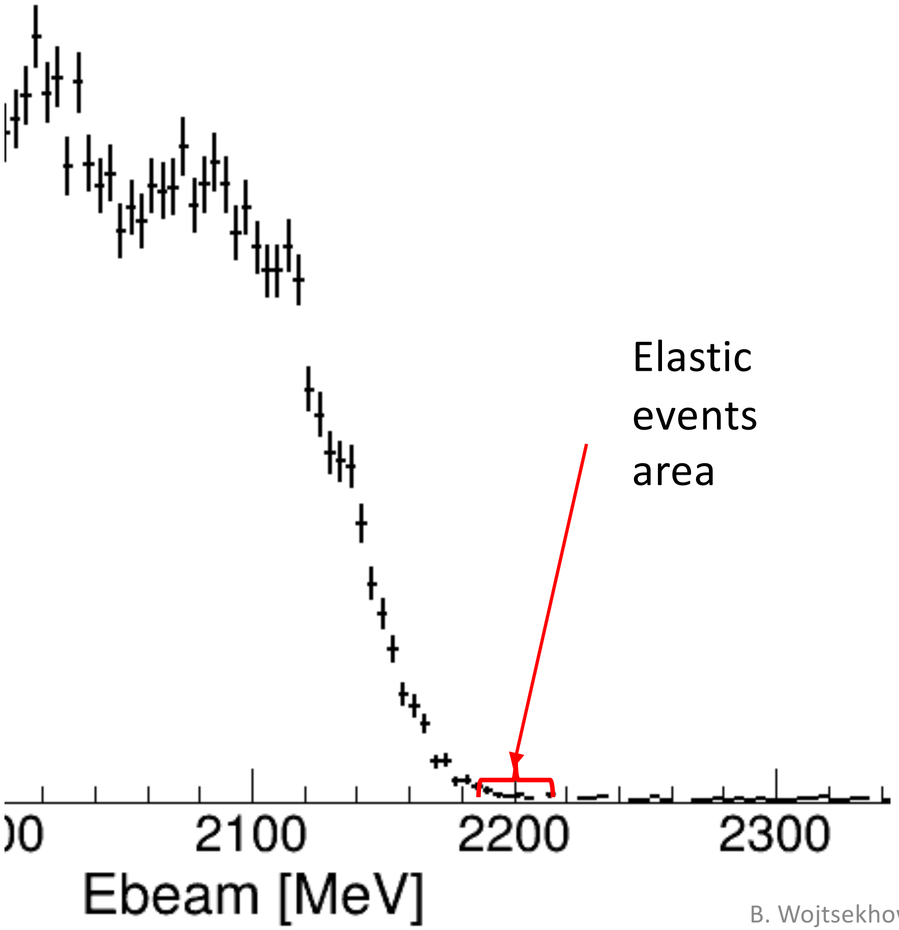
TABLE VI. The beam time request for the AVFF experiment.

Here we are requesting **55 days of total beam time** to do a measurement of the proton Axial-Vector Form Factor at $Q^2 = 1$ (GeV/c)^2. Most of the time (50 days) will be used for statistics collection. We plan to do precision calibration of the time-of-flight system 10 times with 2.5 days included in the total beam time. The calibration will include measurement of the detection efficiency of the neutron arm (TOF and NCAL) by using an LD2 target. We also plan to do five measurements of the beam polarization, which requires 2.5 days (included in the request.)

This experiment will take place in Hall C or Hall A, utilizing a 120 μA 2.2 GeV electron beam with a high degree of longitudinal polarization. Neutrons will be detected using a TOF system plus a hadron calorimeter preceded by a sweeper magnet to eliminate most of the charged particle background. A veto arm detector will be designed to reject events from the two largest background processes: $e-p$ elastic electron scattering and pion photo-production.

The experimental result will be the cross section value of the reaction $p(\vec{e}, n)\nu_e$ at $Q^2 = 1$ (GeV/c)^2. The cross section varies close to linearly with F_A, so the relative accuracy for the Axial-Vector Form Factor is the same as for the cross section, and the projected relative accuracy of F_A **will be 39%** (statistical) with systematics of 5%.

Recent improvement



Event rate	Hz, all cuts	Total events	Accuracy, $\Delta\sigma\,/\,\sigma$
$p(\vec{e}, n)\nu_e$ events	0.0022	9.55k	
background events including contributions from e-p, Al windows, and single-pion (π^+n) production	0.305	1.320M	0.12
background events including the above contributions plus double-pion ($\pi^+\pi^0 n$) production	3.355	14.06M	0.39
Overall systematics			0.05

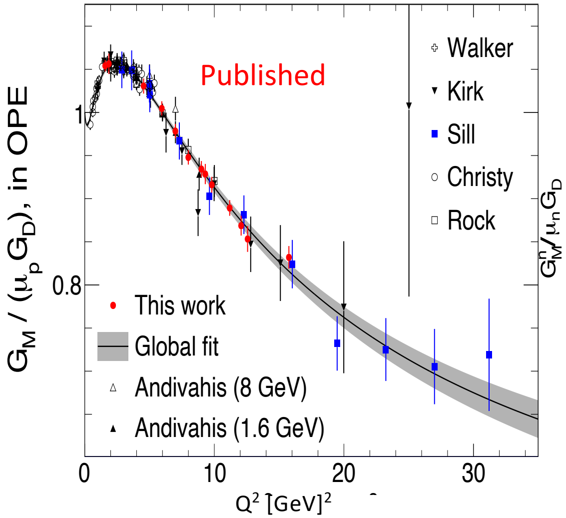
Background fit can use a wider area.

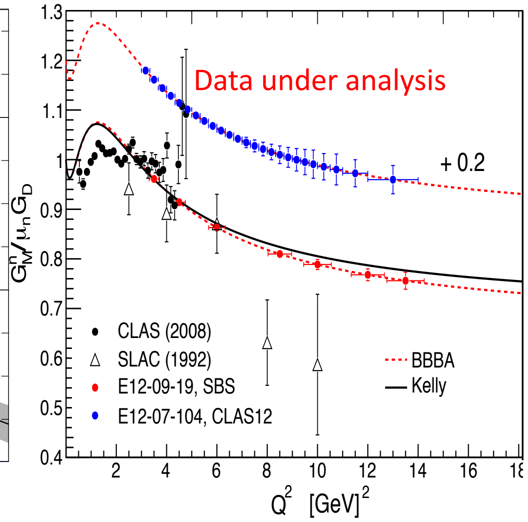
The CC peak use 32 MeV wide area

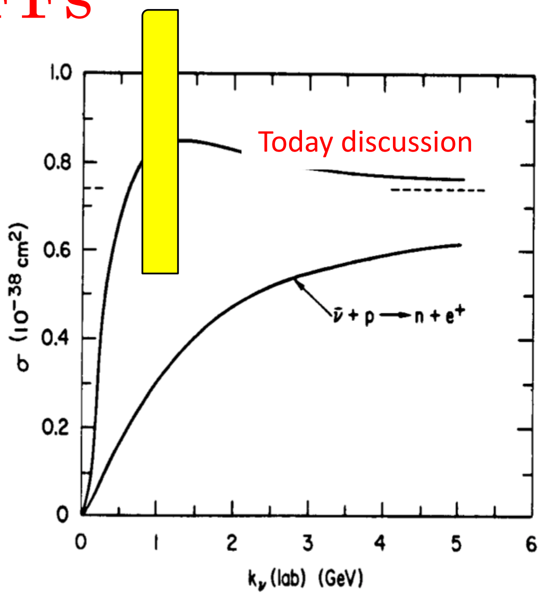
If we use 160 MeV for background fit the result is improvement of the relative accuracy

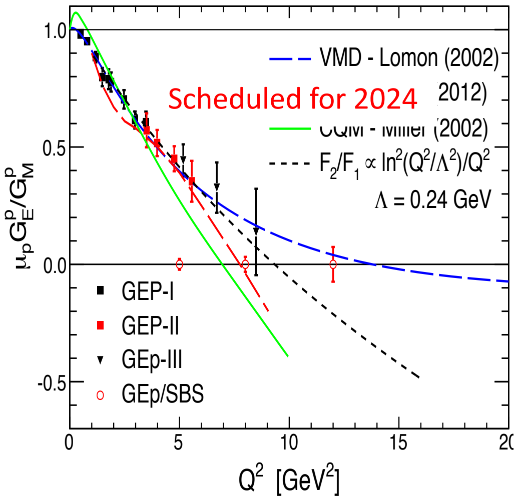
from 0.39 to 0.29

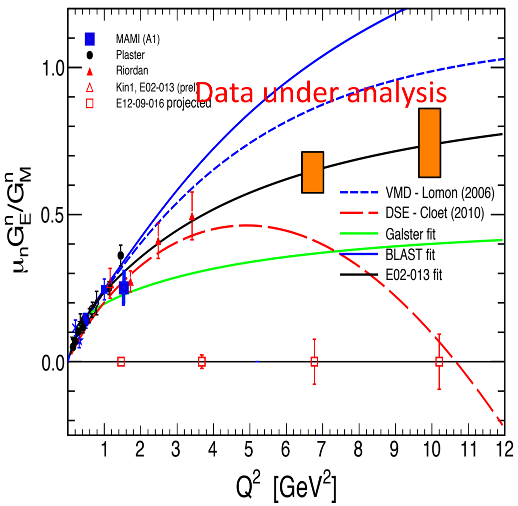
The nucleon elastic FFs











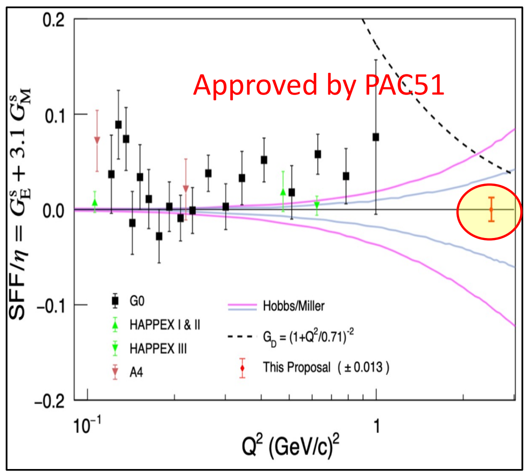
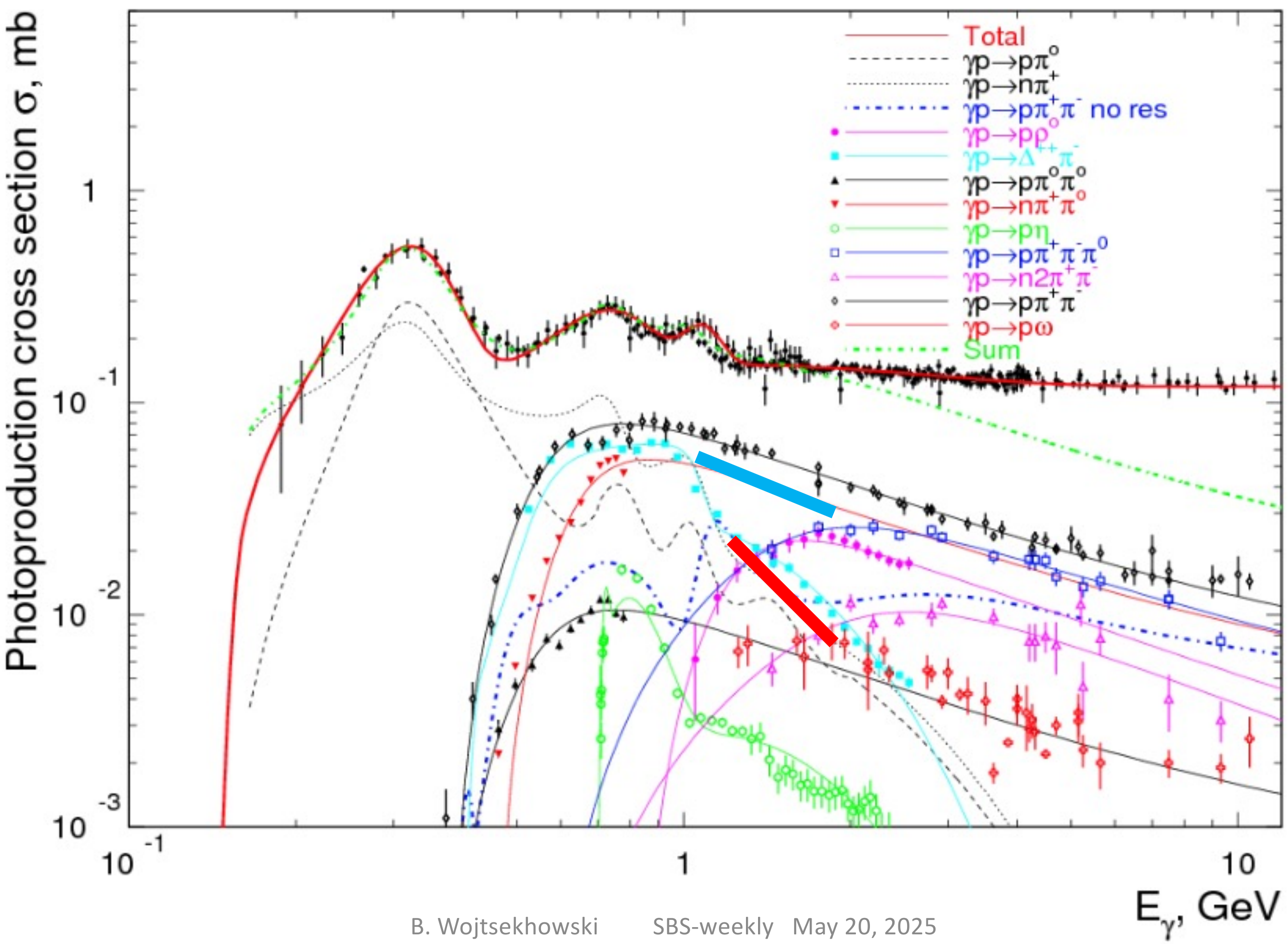


Photo-production reactions (E.Chudakov)

Photoproduction cross section

The full photoproduction cross section along with the partial cross sections important below 2 GeV are presented on the next picture.



Development of the plan for the Test Run

The goals of the test run are:

1. Confirm 100 ps time resolution for neutron with a sample TOF counters and DAQ

2. Measure the rate of background neutrons with energy above elastic peak

The goal 1 could be accomplished with D(e, e' p/n) by using HMS for the electron arm and the LD2 target at standard Hall C pivot. The recoil nucleon will be detected in set of veto plane (exists) and several new high resolution counters (already procured).

The goal 2 ideally requires the measurement at kinematics close to one of AVFF because background strongly varies with the beam energy and recoil angle. However, test of Geant4 prediction could be made with different kinematics which don't require moved pivot.

The measurement will use a LH2 target and a neutron detector which consist of a proton veto plane(counters are available), two TOF planes (30 counters each) and NCAL (available from E864). As a veto arm we will use HMS. The test of Geant4 prediction for 2.2 GeV beam, neutron at 23 degree and HMS at 70 degree..

Additional data could be obtained from Hall D and from Hall C in H(\gamma, p)X - high energy proton tail.