JLAB E12-14-012

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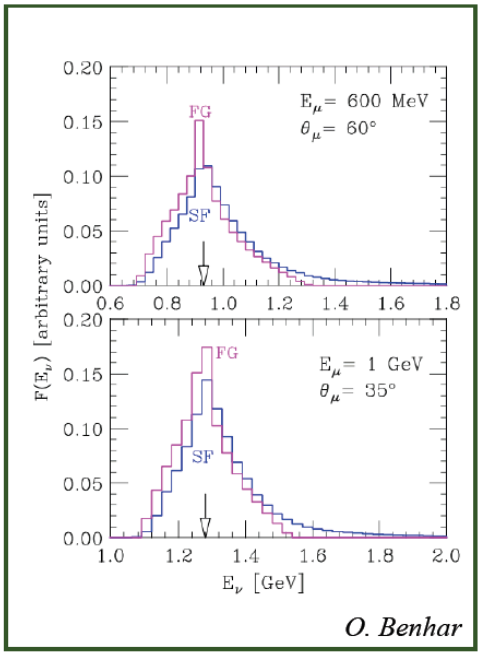
Motivation

Event Rate at far detector:

$$N_{\rm FD}^{\alpha\to\beta}(\boldsymbol{p}_{\rm reco}) = \sum_i \phi_\alpha(E_{\rm true}) \times P_{\alpha\beta}(E_{\rm true}) \times \sigma_\beta^i(\boldsymbol{p}_{\rm true}) \times \epsilon_\beta(\boldsymbol{p}_{\rm true}) \times R_i(\boldsymbol{p}_{\rm true};\boldsymbol{p}_{\rm reco}).$$

$$P(\nu_i \to \nu_j) = \sin^2 2\theta \, \sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

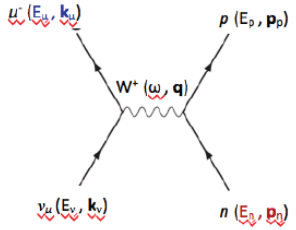


Neutrino Energy: Reconstruction

For CCQE process (assuming single nucleon knock out), The *reconstructed* neutrino energy is

$$E_\nu = \frac{m_p^2 - m_\mu^2 - {E_n}^2 + 2E_\mu E_n - 2\mathbf{k}_\mu \cdot \mathbf{p}_n + |{\mathbf{p}_n}^2|}{2(E_n - E_\mu + |\mathbf{k}_\mu|\cos\theta_\mu - |\mathbf{p}_n|\cos\theta_n)}$$

- Neutrino energy reconstructed using 2 ×10^4 pairs of (|p|, E) values sampled from realistic (SF) and FG oxygen spectral functions.
- The average value ⟨E_ν⟩ obtained from the realistic spectral function turns out to be shifted towards larger energy by ~ 70 MeV



Jefferson Lab Experiment E12-14-012

- Collaboration of 31 physicists, from 8 institutions, based in USA, Europe and Japan
- Approved in July 2014 Scientific Grade A- request coming from the HEP
- Experimental Readiness Review in July 2016
- Data taking started in Feb. 2017
- Data taking completed Mar. 2017

PR12-14-012

Scientific Rating: A-

Recommendation: Approve

Title: **Measurement of the Spectral Function of ^{40}Ar through the (e,e'p) reaction**

Spokespersons: O. Benhar, C. Mariani, C.-M. Jen, D.B. Day, D. Higinbotham

Motivation: This experiment is motivated by the need to model the response of liquid Argon detectors to neutrino beams. This information is important for the LBNF program (and other oscillation experiments) that use liquid Ar. The critical issue is that reconstruction of the neutrino energy depends on the spectral functions of neutrons and protons in ^{40}Ar. The neutrino beam has an energy spread and hence the neutrino flux as a function of energy has to be extracted by simulations that include the correct nuclear physics. A challenge is that the next generation of neutrino oscillation experiments aim at a precision of 1% and hence ensuring that the nuclear corrections are properly addressed is critical. This data will provide experimental input to construct the argon spectral function, thus allowing the most reliable estimate of the neutrino cross sections. In addition, the analysis of the (e,e'p) data will help a number of theoretical developments, such as the description of final-state interactions needed to isolate the initial-state contributions to the observed single-particle peaks, that is also needed for the interpretation of the signal detected in neutrino experiments.

This experiment has significant support from the neutrino community. Letters of support for this proposal were received from the Fermilab management, and spokespeople from LBNE, ArgoNeuT, Captain, LArIAT, and MicroBooNE. The analysis and simulation groups of these experiments will use these data.

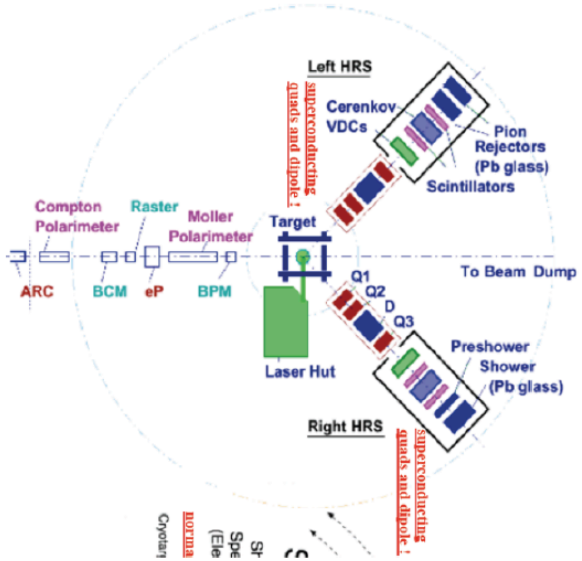
Measurement and Feasibility: The experimenters propose a measurement of the (e, e'p) cross section on argon. Kinematics will be chosen to scan the missing energy domain extending from $E_m \sim 8$ MeV to $E_m \sim 60$ MeV, using the Hall A HRS spectrometers. Similar (e,e'p) experiments have been performed at JLAB and hence this measurement should be straightforward. Kinematical conditions corresponding to interactions with protons moving parallel to the incoming electron beam will be selected to minimize the final state interactions. To test the final-state interaction corrections, and inform such corrections needed for neutrino interactions, the experimenters also propose to measure two days in anti-parallel kinematics where final state interactions should be largest.

Issues: The proposal did not describe how the precision of the proposed experiment would translate into a precision in neutrino oscillation experiments. Given the uncertainty in correction for final-state interactions, it is likely that the systematic errors will be larger than the quoted 3%. However we anticipate that larger errors are likely to be acceptable. The energy resolution will also be larger than the quoted value, but again this appears to be acceptable. The PAC also noted that for anti-neutrino experiments the spectral functions of the neutrons are also important, but this experiment will only determine the proton spectral functions. An appropriate model will be needed to infer neutron spectral functions from the proton data taken in this experiment.

Recommendation: Approve for the requested 9 days of beam time.

Kinematic setups

	E_e	$E_{e'}$	θ_e	P_p	θ_p	$\|\mathbf{q}\|$	p_m
	MeV	MeV	deg	MeV/c	deg	MeV/c	MeV/c
kin1	2222	1799	21.5	915	−50.0	857.5	57.7
kin3	2222	1799	17.5	915	−47.0	740.9	174.1
kin4	2222	1799	15.5	915	−44.5	658.5	229.7
kin5	2222	1716	15.5	1030	−39.0	730.3	299.7
kin2	2222	1716	20.0	1030	−44.0	846.1	183.9



kin1

Collected Data	Hours	Events(k)
Ar	29.6	43955
Ti	12.5	12755
Dummy	0.75	955

kin3

Collected Data	Hours	Events(k)
Ar	13.5	73176
Ti	8.6	28423
Dummy	0.6	2948

kin2

Collected Data	Hours	Events(k)
Ar	32.1	62981
Ti	18.7	21486
Dummy	4.3	5075
Optics	1.15	1245
C	2.0	2318

kin4

Collected Data	Hours	Events(k)
Ar	30.9	158682
Ti	23.8	113130
Dummy	7.1	38591
Optics	0.9	4883
C	3.6	21922

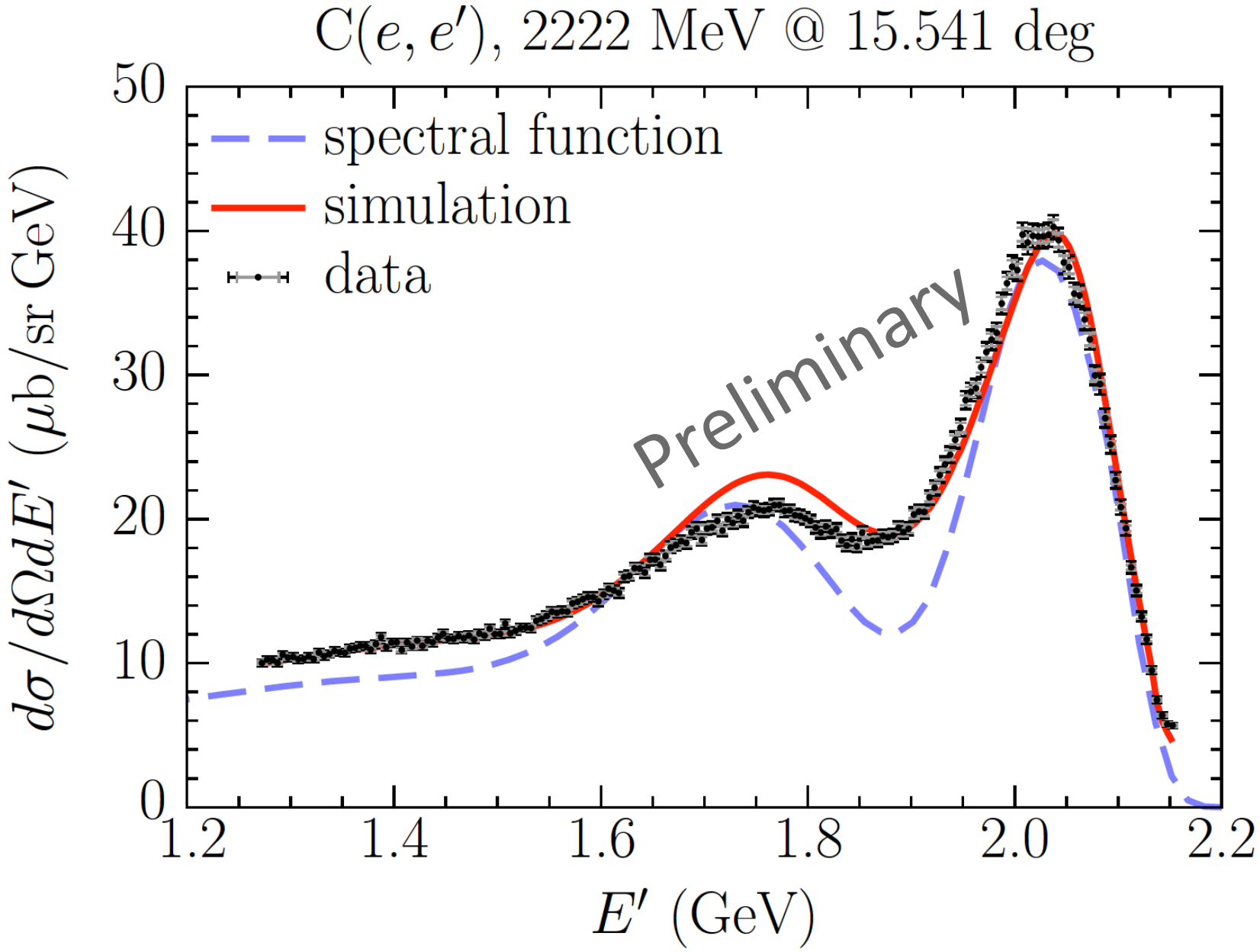
kin5

Collected Data	Hours	Events(k)
Ar	12.6	45338
Ti	1.5	61
Dummy	5.9	16286
Optics	2.9	160

kin5 - Inclusive

Collected Data	Minutes	Events(k)
Ar	57	2928
Ti	50	2993
Dummy	56	3235
C	115	3957

Preliminary results



Future Plan

- Inclusive cross section on C and Ti -- Dec. 2017
- Inclusive cross section on Ar -- Jan. 2018
- Exclusive analysis -- 2018
- First data release -- End of 2018
- Spectral function for Ar and Ti -- by middle of 2019
- Data Release -- End of 2019