RGC Jeopardy Update Document

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We summarize the case for renewing the PAC approval for Run Group C with the full allocated Beam time (185 PAC days) and overall rating of A.

I. INTRODUCTION

Run Group C (RGC) comprises six approved experiments with the CLAS12 spectrometer in Hall B, each scattering polarized electrons from longitudinally polarized protons or deuterons. The RGC experiments were approved for 185 PAC days (60 days on polarized deuterium/ND_3, 120 days on polarized hydrogen/NH_3, and 5 days of auxiliary data). They are:

E12-06-109: Longitudinal spin structure of the nucleon
(Contact: S. Kuhn; PAC rating: A)

E12-06-109a: DVCS on the neutron with a polarized deuterium target
(Contact: S. Niccolai; Run Group proposal, no separate rating)

E12-06-119b: DVCS on a longitudinally polarized proton target
(Contact: F. Sabatie; PAC rating: A)

E12-07-107: Spin-orbit correlations with a longitudinally polarized target
(Contact: H. Avakian; PAC rating: A-)

E12-09-009: Spin-orbit correlations in kaon electroproduction in DIS
(Contact: H. Avakian; PAC rating: B+)

E12-09-007b: Study of partonic distributions using SIDIS kaon production
(Contact: W. Armstrong; PAC rating A-)

The first of two anticipated Experimental Readiness Reviews for RGC was held at JLab on May 30, 2019. The ERR charge and agenda, various supporting documents, committee report, and collaboration response can be found on the review's wiki.[1] The collaboration officially passed the ERR, with relatively few and minor recommendations from the committee, all of which have been addressed. A request for beam scheduling was submitted in August 2019 for 182 calendar days (91 PAC days, or roughly 1/2 of the total approved beam time for RGC). This request was accepted with the sole proviso that running on *any* nuclear targets can be demonstrated not to harm the CLAS12 central silicon vertex detector. A beam test to address this question was conducted in February 2020, and the results appear to alleviate any concerns of running nuclear targets in CLAS12. A Scheduling Request for the remaining 94 PAC days will be made at a later time.

While no official CEBAF schedule beyond December 2020 has been released, all components of the experiment are on track to be ready by summer 2021, and the requested run time could fit into the Hall B schedule for a run beginning in fall 2021. We formally request that PAC 48 renew the approval for RGC and the 185 total PAC days originally awarded to it. This document briefly summarizes the physics goals of Run Group C and provides updates on the work underway to ensure its success.

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[1] https://clasweb.jlab.org/wiki/index.php/RGC_ERR

II. PHYSICS GOALS

The collective goal of the experiments in RGC is to elucidate the spin-dependent valence quark structure of the nucleon. Some of the highlights of the experimental program are:

- Determining the polarization of up and down quarks that carry most of the nucleon momentum (large $x_{Bjorken}$). This goal is part of the core program of Jefferson Lab at 12 GeV to elucidate the longitudinal valence quark structure of the nucleon, and offers a stringent test of predictions from pQCD and other approaches to understand nucleon structure in the framework of QCD (Lattice QCD, Dyson-Schwinger approach, etc.). The continued interest in this physics has been reaffirmed by the 2015 NSAC Long range plan and is evidenced by recent publications [1] and conferences (Strong QCD From Hadron Structure Experiments, November 4-8, 2019, Newport News, VA). RGC will measure both inclusive double spin asymmetries on polarized protons and deuterons, and flavor-tagged asymmetries with pion and kaons in the final state. Together with the measurements on ^{3}He that have just concluded in Hall C, valence and sea quark polarizations over the full range in x from below 0.1 out to 0.8 can be extracted using state-of-the art global DGLAP analyses (see, e.g., the combined global fits by the JAM collaboration [2]).

- Constraining Generalized Parton Distributions of the nucleon through double-spin and target-spin observables in Deeply Virtual Compton Scattering on the proton and the neutron. Together with the corresponding program on unpolarized protons (RGA) and neutrons (RGB), these observables are crucial for an accurate extraction of the three-dimensional (longitudinal momentum and transverse position) quark structure of the nucleon, including a better understanding of the role played by orbital angular momentum in the decomposition of the total nucleon spin.

- Accessing new transverse-momentum dependent parton distributions in the nucleon, in particular those that are correlated with the target spin. Single- and double-spin asymmetries in Semi-Inclusive DIS on polarized protons and deuterons, with detection of pions and kaons in the final state, will provide crucial information on the transverse motion of quarks inside the nucleon that is not accessible without polarized targets. This data is essential for the complete 3-dimensional picture of the nucleon that is a major goal of the energy-upgraded facility at Jefferson Lab.

III. STATUS OF EXPERIMENT PREPARATION

A. Longitudinally Polarized Target

Run Group C will be the first experiments to utilize a new longitudinally polarized target constructed by a collaboration of Christopher Newport University, the Jefferson Lab Target Group, Old Dominion University, and the University of Virginia. The target, designed specifically to operate within CLAS12, will dynamically polarize samples of frozen ammonia (NH_3 and ND_3) at a temperature of 1 K and magnetic field of 5 T. Almost all major components for the target system are in-house and tested, either in final or prototype form. This includes all electronics, microwave generators and waveguide components, 5 T magnet, and 1 K refrigerator and pumps. Preliminary versions of control and monitoring software, a combination of EPICS and LabView, have been written and utilized during target testing in the JLab Target Group laboratory.

Frozen, irradiated ammonia has become the *de facto* standard target material of polarized protons and deuterons for electron experiments at Jefferson Lab. Among its attributes are very high polarizations, high concentrations of protons and deuterons, and good resistance to ionizing radiation. Sufficient quantities of NH_3 and ND_3 to complete the Run Group C experiments are on hand at UVa.

The CLAS12 solenoid will provide the 5 T field for polarizing the target samples in the longitudinal direction [3]. For optimum dynamic nuclear polarization, the field should have a uniformity of about 10^{-4} (100 ppm) over the volume of the target sample. Field maps of the solenoid indicate that it is marginal in this respect, and so the polarized target is designed to incorporate thin, superconducting shim coils inside its 1 K refrigerator. Extensive modeling has been performed to validate the feasibility of this approach [4], and the JLab Target Group has considerable experience producing small superconducting coils of this nature [5].

The target samples will be cooled to 1 K using a bespoke, high cooling power ^{4}He evaporation refrigerator currently undergoing tests in the Target Group's lab [6]. Three cool-downs have been performed to date, each highly successful. The refrigerator has a base temperature below 1 K, a cooling power of 1 W at 1.08 K, and a daily consumption of liquid helium under 50 liters. It features a number of innovative design elements, based on previous experience at JLab, that are intended to make it more reliable and more easily serviced, and to reduce the overhead of its operation.

Most notable is a retractable helium bath for the target samples that will significantly reduce the time required for the routine operations of sample annealing and replacement.

Dynamic nuclear polarization of test samples of two-part epoxy doped with the paramagnetic radical TEMPO (chosen for convenient handling) has also been demonstrated using the new refrigerator, with the FROST 5 T warm-bore solenoid standing in for the CLAS12 solenoid. Proton polarizations during these tests were measured using protoypes of a new Q-meter system designed and constructed at JLab [7]. The new system is intended to replace the decades-old Liverpool Q-meter, which is no longer in production [8].

A new target insertion cart for the Hall B rail system is now under construction that will permit precise alignment of the system on the Hall B beam line. Furthermore, all essential electronic, vacuum, and piping components for the target will be mounted directly on the cart, reducing the time needed to install the system in the hall. Design is also underway of beam-ready replacements for certain prototype components of the refrigerator, such as the retractable helium bath and the thin, downstream portion of the vacuum chamber. These will be built in the near future, and the target system can be available for installation in Hall B in summer 2021.

B. Beam Raster

To maintain high polarization, the ionizing radiation dose to the target must be evenly distributed to its entire volume by rastering the electron beam over the 1 cm radius of the target. This is accomplished using two upstream sets of x-y dipole magnets synchronously driven by two high-current, dipolar power supplies. The electron beam is deflected by the first set of magnets and then made perpendicular to the target by the second set, akin to a collimated beam. One power supply feeds both x magnets, arranged such that the magnetic fields are 180° out of phase; the y magnets operate in a similar fashion. RGC will be the first experiments to utilize a rastered beam in Hall B since the 12 GeV energy upgrade.

It has been determined that the existing raster magnets from the 6 GeV program in Hall B are adequate for the RGC experiments, and appropriate locations on the beam line have been specified. A new spiral raster control module for the power supplies has been designed, constructed, and tested by the JLab Fast Electronics Group, and ±240 A power supplies from Danfysik are on hand. Together, they will raster the electron beam in a spiral pattern at constant linear speed, thus giving a uniform illumination over the face of the target sample. The period of a full spiral-in, spiral-out cycle is 5 s.

C. New Moller Shield and Drift Chamber Occupancies

D. Simulation

IV. SUMMARY

Since the various experiments comprising RGC have been approved, the community's interest in this program has only grown and the physics case remains compelling. No comparable data have been collected anywhere or are likely to be available in the foreseeable future. The collaboration and Jefferson Lab have made a major investment in the equipment needed for RGC, including substantial support by an NSF MRI awarded to a consortium of universities (CNU, ODU, and UVa). Members of the collaboration have invested significant time and effort into all aspects of the preparation of this experiment - from prototyping and building the polarized target to simulations and design of all necessary beam line equipment. The program to be carried out within RGC is a major part of the overall experimental program approved for CLAS12. The experiment will be ready to run anytime after summer 2021. We request that the PAC reaffirm the original approval of this run group, and give it the highest rating.

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