Addendum to Scheduling Request:

Hall B Run Group F (“BONuS12”)

S. Bültmann, S. Kuhn, M.E. Christy, H. Fenker, K. Griffioen, C. Keppel, W. Melnitchouk (Co-Spokespersons)

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I. INTRODUCTION

Experiment 12-06-113 [1] (also known as “BONuS12” or Run Group F in CLAS12) was first proposed in 2006 and conditionally approved for 42 100% efficient days by PAC30. It was resubmitted in 2010 and fully approved, with rating “A”, by PAC36. PAC41 selected BONuS12 among the high-impact experiments to run early in the 12 GeV era at Jefferson Lab (this designation was shared with the MARATHON experiment [2]). In May of 2017, the experiment underwent an Experimental Readiness Review (ERR) and was approved to go forward with a beam time request, which was submitted in July 2017. As part of the ERR, we provided a schedule showing that BONuS12 will be ready for installation into CLAS12 by December 31, 2018. At present, we are still on course to meet this milestone. In view of the widely recognized importance of the physics (see below), and the large investment in resources and manpower (including students and postdocs) the collaboration has mounted, we urge that BONuS12 be scheduled as soon as possible after that date.

Following the most recently released accelerator schedule (May 2018), it appears that Hall B will be occupied by other run groups until November 25, 2019. We are submitting this addendum to our beam time request to advocate that immediately following that date, installation for BONuS12 should begin and all of the BONuS12 approved beam time should be scheduled for the Spring 2020 run, if at all possible (consistent with overall funding for the lab). Any further delay would not only severely impact the younger members of the collaboration, but would also be detrimental to obtaining timely results and furthermore would result in a significant waste of DOE funds and JLab resources and available beam time. In the following, we outline the arguments in favor of this request.

II. THE BONUS EXPERIMENT AND ITS PHYSICS IMPACT

The goal of the BONuS experiments is to study a wide range of electron scattering observables, over a wide kinematic range, on a “nearly free” neutron. Among the physics topics addressed by ”BONuS” are measurements of the free neutron structure function $F_2^n(x)$ over a large range in x and Q^2, including its asymptotic behavior as $x \to 1$ which will help determine the ratio of d and u quark distributions (d/u) in this limit. Further subjects to be studied include semi-inclusive and exclusive channels, and nuclear physics topics like the EMC-effect in deuterium and final state interactions affecting the outgoing proton in $d(e, e'p)X$.

To approximate a free neutron target, the BONuS collaboration uses a deuterium target and detects the low energy recoil proton, which allows us to correct for the initial (Fermi) momentum of the neutron in the deuteron and select scattering events off a nearly on-shell neutron. In the 5.3 GeV BONuS experiment with CLAS in 2004, the neutron structure function was extracted over a kinematic range covering both the resonance and DIS region, leading to a significant number of publications [3–7]. The large interest in these results is reflected in the number of citations (over 100), including by several theoretical papers on Final State Interactions (FSI) [8] and PDFs [9–11]. The results have even been quoted in a text book [12].

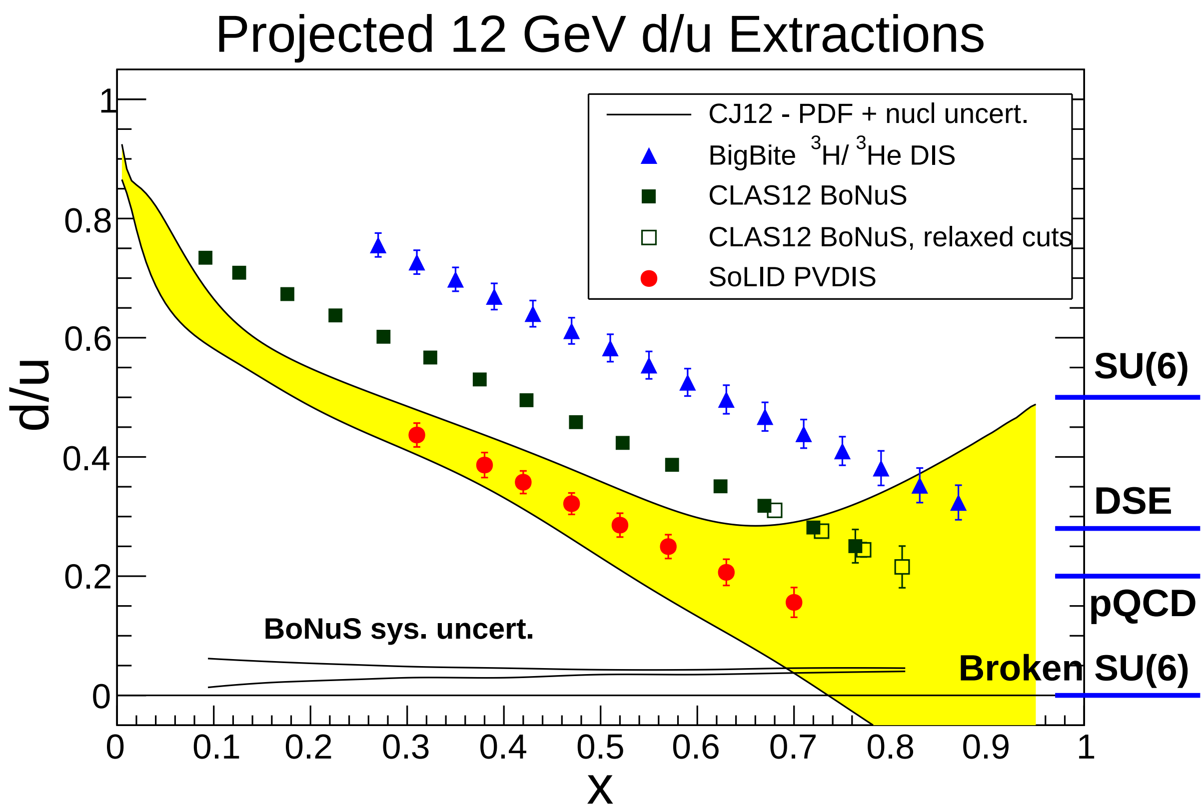

FIG. 1. Anticipated experimental uncertainties on the ratio of d over u quarks vs. Bjorken-x from various Jefferson Lab experiments. The expected BONuS12 data are shown as dark green squares, with statistical error bars (invisible except for the highest points in x), and systematic uncertainties indicated by the black lines near the axis (lower line: point to point systematic uncertainties; upper line: overall uncertainty including normalization). Several predictions for the asymptotic value of the ratio are indicated on the right axis. (Note: the data points labeled "BigBite" are actually for the "MARATHON" experiment, which ran with the HRS instead of the BigBite detector.)

The BONuS program will continue with the CLAS12 spectrometer and a new recoil detector, which will allow us to extend our knowledge of neutron structure and the ratio of d to u quark PDFs to the highest x possible, $x \approx 0.8$ (see Fig. 1). The expanded kinematic range and the much higher luminosity will allow us, for the first time, to answer definitively the question whether the asymptotic ratio of down to up quarks at the limit $x \to 1$ follows the expectations of pQCD (in particular parton helicity conservation [13]), or one of the alternative models indicated on the right vertical axis of Fig. 1. Experiment E12-06-113 (also dubbed "BONuS12" [1]) has been fully approved by the Jefferson Lab PAC with the highest rating ("A"). Furthermore, PAC41 selected the BONuS12 experiment, together with MARATHON [2], as one of the high impact experiments that should be run early in the 12 GeV program at Jefferson Lab.

A. Timeliness and Competitiveness of the expected BONuS12 results

Experiments to determine the valence quark distributions (PDFs) $u(x), d(x)$ in the nucleon continue to be of high interest. This information is necessary, for instance, to access the asymptotic behavior (as Bjorken $x \to 1$) of the ratio of d over u quark PDFs. This ratio depends sensitively on the mechanism by which spin-flavor symmetry is broken and has therefore been a longstanding problem of high theoretical interest [13, 14]. At the same time, quark distributions at large Bjorken-x are also needed as input for cross section calculations at colliders such as the LHC, to extract spin structure functions of the neutron from measured asymmetries [15, 16], for tests of quark-hadron duality in the neutron [17, 18] and as ingredients for precision measurements of the EMC effect [19]. The importance of measuring these PDFs has been recognized in the latest NSAC Long Range Plan [20], where the three Jefferson Lab experiments addressing this topic are described on p. 15 (see Fig. 1 which appears as Fig. 2.3 in the long range plan).

In Spring 2014, PAC41 was charged to select a "High Impact" subset of the approved experiments at that time. The purpose of this subset was to form a high-priority foundation for the first 3-5 years of production running, covering the years 2015-2020.In their report, PAC41 "split" a high impact rating between BONuS12 and MARATHON, showing 21 days for each in their table on p. 7. A footnote in this table adds "42 days High Impact for the experiment that runs first; experiments are equally important & both are essential". In their written report on "unpolarized d/u", the summary reads "The Committee identifies the measurement of the $x \to 1$ limit of d/u as having extremely high impact. At least 40 PAC days are necessary to measure this important quantity. The committee finds no basis on which to select one experiment over the other as the first to run, and feels that both experiments must ultimately be performed." Their summarry states: "d/u : 42 days for BONUS12 (E12-06-113) or MARATHON (E12-10-103)".

In the meantime, the MARATHON experiment has completed its data taking run in the past year. We want to stress that this doesn't make a timely run of BONuS12 any less urgent, as the two experiments really measure different observables and have complementary strengths and weaknesses:

- We first point out that the last MARATHON data point shown in Fig. 1 was not measured, and the second to last data point was measured with similar "relaxed W cuts" as is planned for BONuS12. Hence, the expected statistical precision and kinematic coverage of BONuS12 data will be practically the same at very large x as the data collected with MARATHON, while being significantly more precise in the intermediate x region. Furthermore, for all but the lowest and highest x, BONuS12 will cover a range of a factor 1.5–3 in Q^2 for each x, allowing us to extract higher twist and pQCD scaling violations.

- BONuS12 and MARATHON results will have very different systematic and model uncertainties. Extraction of the ratio $F_2^n(x)/F_2^p(x)$ from MARATHON data relies on models of the EMC effect where the effect in ^{3}H and ^{3}He is essentially the same, so that it cancels in the ratio. This assumption does not hold in models [21] of the EMC effect that correlate PDF modifications in nucleons to those nucleons being in high-momentum short range correlations. Further, in quark-meson coupling models of the EMC effect [22], u and d quark distributions are modified differently in $N \neq Z$ nuclei. This difference could apply to ^{3}H and ^{3}He. Finally, even absent any explicit off-shell effect, MARATHON effectively measures PDFs smeared by the Fermi motion of nucleons inside the target nuclei. If the underlying PDFs have different functional forms near $x \to 1$, this may again lead to different EMC ratios for proton vs. neutron structure functions. On the other hand, while BONuS12 largely eliminates Fermi smearing, it relies on binding and Final State Interaction (FSI) effects being minimized for backward, slow-moving spectator kinematics. This is supported by theoretical calculations [8] and can be tested with the data themselves, but of course a small model uncertainty remains.

- MARATHON also measured DIS on a deuterium target to directly address the question of the magnitude of the EMC effect in both ^{3}H and ^{3}He. However, to use this information to extract the full modification of both proton and neutron structure functions in these nuclei, the EMC effect in Deuterium itself must be known. BONuS12 will determine this ratio of deuterium to free proton and neutron structure functions more directly, and over a wide range in x and Q^2. This will not only help to interpret MARATHON results, but also anchor the expected results from the large program of other planned measurements of the EMC effect at Jefferson Lab in the 12 GeV era (see pages 19-21 in the Long Range Plan).

In summary, only a combined analysis of both data sets can give us full confidence that systematic and model uncertainties are sufficiently under control and that reliable information on the d/u PDF ratio can be extracted. For this reason, for a timely result on the ratio d/u, BONuS12 must be scheduled as soon as possible.

III. RECENT PROGRESS AND STATUS OF BONUS12

The centerpiece of BONuS12 is a low-momentum proton recoil detector that will tag DIS events on the neutron inside deuterium by detecting and reconstructing spectator protons above 70 MeV/c momentum. This detector is a radial time projection chamber (RTPC) with triple GEM amplification at its cylindrical perimeter and a 96x180 pad readout board to fully reconstruct (in three dimensions) the tracks of low-momentum protons. The design and construction of this RTPC is a collaborative effort between Hampton University (M.E. Christy, A. Nadeeshani, I. Albayrak), William and Mary (K. Griffioen, C. Ayerbe), Old Dominion University (S. Kuhn, S. Bültmann, G. Dodge, G.

Charles, M. Hattawy, J. Poudel, T. Hartlove) and Jefferson Lab (R. Miller, M. Zarecky/C. Wiggins, C. Cuevas, M. Taylor, H. Fenker, G. Jacobs, M. McMullen). Further assistance is provided by UVa (N. Liyanage, K. Gnanvo) and VUU (N. Kalantarians). Additional ODU students (P. Pandey, I. Neththikumara and D. Akers) are testing various components of the detector.

The readout electronics is using the MVT DREAM electronics and is being tested at ODU (J. Poudel, I. Neththikumara, M. Hattawy) using the existing EG6 RTPC prototype. We are also consulting with people from CEA/Saclay (Stephan Aune, Irakli Mandjavidze) on all aspects of the DAQ system and the changeover from standard CT operation to BONuS12 RTPC operation. Two ODU Ph.D. students and a postdoc (N. Dzbenski, D. Payette and M. Hattawy) are developing complete GEANT4/GEMC simulations of the experimental set up (including CLAS12 and the RTPC) as well as the necessary data analysis software in the COATJAVA framework.

At the moment of this writing, the design of the RTPC and ancillary parts is nearly complete. We have built the first of three GEM foil mandrels and have developed a successful method of producing GEM cylinders in a clean room environment. We also have in hand a mandrel for the readout pad-board and have tested the process of forming it into a cylinder with various prototypes. We have all necessary GEM foils in hand and are ready to procure the remaining mandrels for a complete 3-foil amplification stage. The remaining tasks are to complete drawings of all parts for the innermost ground and cathode foils, and some ancillary parts for the installation. We estimate 7.2 additional FTE weeks of design work and 8 FTE weeks of machine shop time to complete all remaining parts for the RTPC and its installation. In addition, we estimate 3 FTE weeks of design and 2.5 FTE weeks of machine shop time to complete all parts of the target and its gas system. Finally, the drift gas system and slow controls for the RTPC are being developed by a collaboration between VUU, VCU, JMU and Jefferson Lab. ODU is designing and building a Drift Gas Monitoring System. Apart from the latter, all parts have been procured or are on order. The full system will be ready for tests of the first RTPC in November 2018.

On the electronics side, we have acquired a HV power supply for the GEMs and cathode, and have designed all guard and HV circuit boards for the RTPC. The electronic layout of the readout padboard is complete and a fully instrumented set of padboards can be ordered within the next month. We also have completed the gross layout of the adaptor boards that will carry the overvoltage protection circuits and connect the padboard to the cables carrying the signals to the DREAM FEUs. Finally, we will have to procure about 300 quadruple SAMTEC cables with MEC-8 connectors on both sides to connect the RTPC with the FEUs. This is the most significant remaining expenditure, expected at $100k. We are ready to order these cables as soon as funds are available.

We are on track to have all necessary pieces in hand to begin assembly of the first complete RTPC in September 2018, and test it with cosmic rays and radioactive sources by the end of the year. A second RTPC will be built early in 2019 to serve as a "hot swap" backup.

Overall, we are on track to complete the experimental equipment for BONuS12 by the end of 2018, as originally anticipated in our ERR one year ago. We therefore will have plenty of time during 2019 to test all aspects of the hardware and software and be ready for a successful installation to begin on or before November 25, 2019. The following Table I shows the remaining estimated required resources and and completion dates for this project.

Item	Completion Date	Resources Required ($ or hours FTE)
RTPC components	October 2018	288 h design and 320 h machine shop time
Target system	December 2018	120 h design, 100 h machine shop, 160 h assembly
Readout Padboards	September 2018	Quoted for $9300
Adaptor boards	September 2018	Estimated at $10,000
Signal cables	September 2018	Estimated at $100,000
Gas system	November 2018	All resources accounted for
Slow Controls	Early 2019	80 h
DAQ software	December 2018	400 FTE man hours (JLab and ODU)

TABLE I. Remaining tasks for BONuS12 readiness.

IV. INSTALLATION SCHEDULE

Assuming a start date of November 25, 2019, we are confident that we can successfully switch from standard CLAS12 operations to the BONuS12 configuration by the end of January, 2020, to be ready for a Spring 2020 run for BONuS12 (RG F). This assumes about one week each for the disassembly of the beamline/target after conclusion of RG B, for the disassembly of the CVT (MT and SVT), and for the uncabling and storage of all unneeded components. This would be followed by one week each for the mechanical installation of all RTPC components, for the installation and testing of all cables and gas supplies, for the re-installation of the FMT and ancillary supplies as well as the fiducialization of all relevant elements, and for the insertion and alignment of the entire system back into CLAS12. Depending on available time, up to 1 week of cosmic ray test data can be taken in situ to test all aspects of the DAQ and RTPC operation, to be ready for beam operation early in February 2020.

We note that a high premium should be put on completion of the BONuS run during Spring 2020, so that the summer of 2020 can be used to revert CLAS12 to standard (or polarized target) operation without losing any beam time in the Fall. Given 42 approved

PAC days, this corresponds to 12 weeks of beam operation (until early May 2020), similar to the past Spring 2018 run. Given that the precision of the highest x data points is entirely driven by statistics, any significantly shorter run would result in data that may not be publishable by themselves and in any case will not reach the stated accuracy on the ratio d/u at large x.

V. SUMMARY

We are requesting that BONuS12 installation and running be the highest scheduling priority after the end of the presently scheduled partial run of RG B. Installation should begin November 25, 2019 at the latest; ideally, if a sufficient amount of data for RG B could be collected before the anticipated shutdown and low-energy run in summer 2019, earlier installation during that summer would be highly desirable. At a minimum, some parts of the BONuS12 setup should already be pre-staged in the Hall during that time. In either case, we are confident that BONuS12 will be ready for a successful run at its full approved beam time.

Further delay of BONuS12 would have many negative consequences, some already spelled out in the preceding sections. Apart from the loss of timely data needed in their own right and to support many other experiments at Jefferson Lab, a delay would also engender a significant waste of manpower, resources and optimal use of beam time. Among other reasons, the contract with CEA/Saclay to support changes to the MT configuration ends with the end of 2019, at which time a changeover from standard CLAS12 to BONuS12 configuration would require new manpower and training. Having BONuS12 stretch over the summer of 2020 would result in significant idle time, balanced by the need to use precious beam time to change back to other configurations. Other high-priority components of the CLAS12 experimental program, e.g., the installation of the longitudinally polarized target, would be significantly delayed. Furthermore, the expertise and accomplishments of the large number of students, postdocs and faculty members that have already invested a large effort in the preparation of BONuS12 might be wasted, since at least most graduate students are expected to complete their doctorates in summer of 2020.

Finally, BONuS12 has been recognized by the funding agencies (DOE and NSF) as a high priority part of the early Jefferson Lab at 12 GeV program. This is born out by the substantial funding received by BONuS collaborators above and beyond their regular research grants, specifically for components and manpower directed towards BONuS12 preparation. A summary of most of these expenditures is shown in Table II. Timely installation and running of BONuS12 should ensure an optimal return on this substantial

Funding Agency	Institution and Purpose	Amount in $
DOE	W&M gas system acquisition	10k
DOE	ODU postdoc and student support, DREAM FEUs, HV PS	166k
State of VA	ODU acquisition of GEM foils	30k
4VA Fund	ODU undergraduate student labor	5k
NSF	HU "EAGER" grant for cathode development	300k
NSF	VUU "RIA" grant for slow controls development	178k
Total		$\approx$ 700k

TABLE II. Expenditures by funding agencies specific to BONuS12 project.

investment.

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