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Research Management Plan (RMP)
for the SBS projects in Hall A Jefferson Lab

October 2011

1 Introduction

This document describes the plans of a group of institutions within the Electro Magnetic Form Factor (EMFF) collaboration for the management of the research efforts connected with the construction and operation of the Super Bigbite Spectrometer (SBS) in three Form Factor experiments. In contrast to construction, research efforts are not funded by the construction SBS projects but from the research funding of the individual groups involved in the SBS projects.

Research efforts include simulations of the detector performance, development and execution of calibration procedures for the detector, commissioning of the detector, development of analysis software, physics analysis and operation of the detector. This research management plan (RMP) is part of the documents required by the DOE Nuclear Physics Program office for the 10/13-14/2011 review. It is also not the scope of this document to justify the physics case for the SBS. The physics justification is an ongoing process that has started with the SBS proposals for the JLab PACs and for the Science Review. This RMP addresses the activities of the participating institutions in the time between FY12 and the experimental run of GEp(5). FY18 is expected to be the last year of the EMFF program for the SBS[1]. The physics activities listed for the individual institutions reflect the physics interest of those institutions. The SBS projects are designed to perform the Form Factor experiments at high momentum transfer with the 12-GeV upgrade of JLab accelerator. The scope of the construction project is defined as building a new magnetic spectrometer in Hall A with related infrastructure, as well as a set of new detectors and trigger/DAQ electronics. The research under this RMP includes the research activity essential for the development and commissioning of the instruments as well as for the preparation and analysis of the future experimental data.

2 Research Goals

The development of an understanding of nucleon structure and the nature of quark confinement is one of the most important endeavors facing physics today. Indeed, among other things, the dynamical generation of mass within the nucleon largely answers one of the great questions facing science: What is the origin of mass? While the Higgs mechanism is often invoked in response to this question, David Gross, in his Nobel Lecture in 2004 stated, “This is incorrect. Most, 99% of the proton mass, is due to the kinetic and potential energy of the massless gluons and the essentially massless quarks, confined within the proton.” During his lecture Gross at one point calls the understanding of the non-perturbative region of QCD “ ... one of the most important areas of theoretical physics.” The structure of the nucleon is to nuclear physics, in the early 21st century, what the structure of hydrogen was to atomic physics during the early 20th century.

While a true solution to QCD in the non-perturbative regime remains elusive, enormous progress has been made. Sophisticated phenomenological models have helped to elucidate the relevant degrees of freedom within the nucleon. Some of these models even come tantalizingly close to something approaching an analytical approach. Perturbative QCD (pQCD), while it cannot be used to calculate such underlying quantities as form factors and structure functions, can predict how certain of these quantities evolve with Q^2. Theoretical advancements such as the development of Generalized Parton Distributions (GPDs) have even allowed us to understand both structure functions and form factors within a single unifying framework. In addition, lattice QCD, which may ultimately provide arbitrarily accurate numerical solutions to just about any question we may pose, has made stunning progress. Again in his Nobel Lecture, Gross notes the enormous progress in Lattice QCD in “ ... achieving now reliable results that fit the low-lying spectrum to a few percent!”

One of the critical factors driving progress in understanding nucleon structure is the availability of precision experimental results at the largest possible Q^2. The observation of the surprising Q^2-dependence

[1]Preliminary physics program on Hall A was presented in: `http://hallaweb.jlab.org/collab/meeting/2011-summer/talks/day1/BobM_HA_june2011.pptx`

of G_E^p/G_M^p has generated more theoretical papers than any other result to come out of JLab. Measurements of G_E^n/G_M^n, both at JLab and at MIT/Bates, were explicitly mentioned in the 2007 NSAC Long Range Plan (LRP). Regarding measurements of the ground-state form factors after the CEBAF upgrade, the 2007 LRP states that "Such measurements remain the only source of information about quark distributions at small transverse distance scales." Indeed, most of the current theoretical approaches to understanding nucleon structure, including phenomenological models, analysis based on GPDs and lattice calculations, require input and constraints from form-factor measurements.

Three measurements of the ground-state electromagnetic form factors are planned: one of G_E^n/G_M^n, one of G_E^p/G_M^p, and one in which a detailed comparison of G_M^n and G_M^p will be made. These three measurements, together with a very precise measurement of G_M^p using the Hall A HRS Spectrometers (not part of the Super Bigbite Program), will collectively provide precise determinations of all four nucleon form factors with unprecedented reach in Q^2. The Figures-of-Merit of these measurements represent an improvement by a factor of between 10 and 50 over all past and proposed efforts. Together with small projected systematic errors, the Super Bigbite Spectrometer will provide unique accuracy in a Q^2-regime with impressive discovery potential.

2.0.1 Neutron Electromagnetic Form-Factor Ratio G_E^n/G_M^n up to Q^2 = 10 GeV^2

The GEn(2) experiment (E12-09-016), which was first approved in January of 2009 by PAC34, will measure a double-spin asymmetry in quasi-elastic scattering of polarized electrons from a polarized ^{3}He target using the reaction $^3\overrightarrow{\mathrm{He}}(\vec{e}, e'n)pp$. The scientific rating (A-) and beam time allocation for GEn(2) (50 days) were assigned by PAC35. We have adjusted the experimental plan and projected accuracies to accommodate the allocated beam time (see Fig. 1).

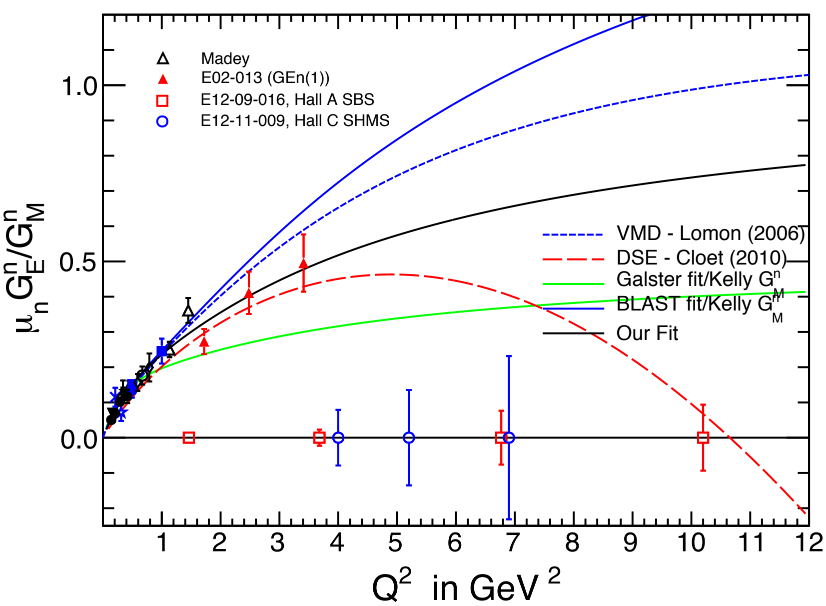

Figure 1: Shown are existing data and projected errors for measurements of the ratios of the electric and magnetic form factors of the neutron. The projected errors for the measurements made with the Super Bigbite Spectrometer are shown by the open red squares. We show published data including those of Madey *et al.*, and the results of GEn(1). We also show the projected errors of GEn(2) in an approved 50-day run, and C12-11-009 in a 60-day run with SHMS (open blue points), for which the projected accuracies are corrected for the known difference between the analyzing power of pp and pn scattering, which was not taken into account by the authors of the PR12-11-009 proposal.

A schematic representation of the experimental setup is shown in Fig. 2. The scattered electron will be detected using a modified version of the BigBite spectrometer. The BigBite detector package includes the GEM tracking system that is being built as part of the Super Bigbite Spectrometer projects. The recoil neutron will be detected using a large segmented hadron calorimeter that will also be used in the proton arm of GEp(5). For GEn(2), the Super Bigbite magnet itself will be located between the target and the hadron calorimeter, and will make it straightforward to distinguish between charged and neutral quasi-elastic events.

Neutron form factors, E12–09–016 and E12–09–019

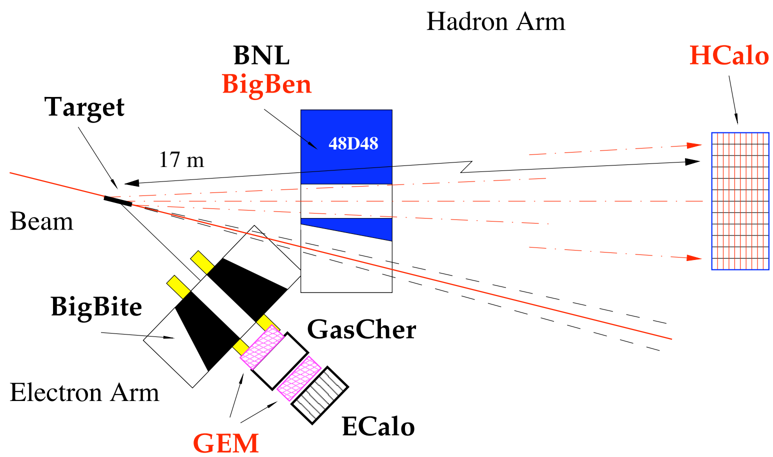

Figure 2: Shown is a schematic representation of the setup that will be used for both the GEn(2) (E12-09-016) and the GMn experiments (E12-09-019). The target will be polarized ^{3}He for GEn(2) and deuterium for the GMn experiment, most other components are identical.

GEn(2) will require an increase in effective usable luminosity over GEn(1) of more than an order of magnitude. It should also be noted that the effective luminosity of GEn(1), when it was performed, represented more than an order-of-magnitude increase in effective luminosity over earlier experiments to measure G^n_E. The gains in GEn(1) were due largely to three factors: 1) the use of a highly-optimized polarized ^{3}He target, 2) the ability to collect excellent statistics using the open-geometry dipole spectrometer BigBite, and 3) the use of what was then (and probably still is) the world's largest dedicated neutron detector. The additional gains that will come with GEn(2) result from 1) a further upgraded polarized ^{3}He target that will be able to tolerate beam currents in excess of 60 μA while delivering even higher polarization, 2) greatly increased rate-handling capability using GEM technology, 3) the use of the Super Bigbite magnet to greatly simplify the identification of charged events, 4) a neutron detector (hadron calorimeter) with suppression of background by more than a factor of 200, and of course, 5) the higher beam energy available from the upgraded CEBAF.

2.0.2 Proton Form-Factor Ratio Measurements up to Q^2= 12 GeV^2 using Recoil Polarization

GEp(5) (E12-07-109) was approved by PAC32 in August of 2007 and was the experiment that provided the original motivation for the Super Bigbite Spectrometer. It will measure the ratio G^p_E/G^p_M using the polarization-transfer method in the reaction $p(\vec{e}, e'\vec{p})$. The polarization of the recoil proton will be measured using a large-acceptance spectrometer, based on the Super Bigbite magnet, that will incorporate a double polarimeter instrumented with GEM trackers and a highly-segmented hadron calorimeter. The electron will be detected in coincidence by a electromagnetic calorimeter that is sometimes referred to as "BigCal". PAC35 allocated 45 days of beam time for the proposed measurement and recommended a maximum value of Q^2 12 GeV^2. These parameters were used to readjust the plan of measurements shown below. The projected results are shown in Fig. 3.

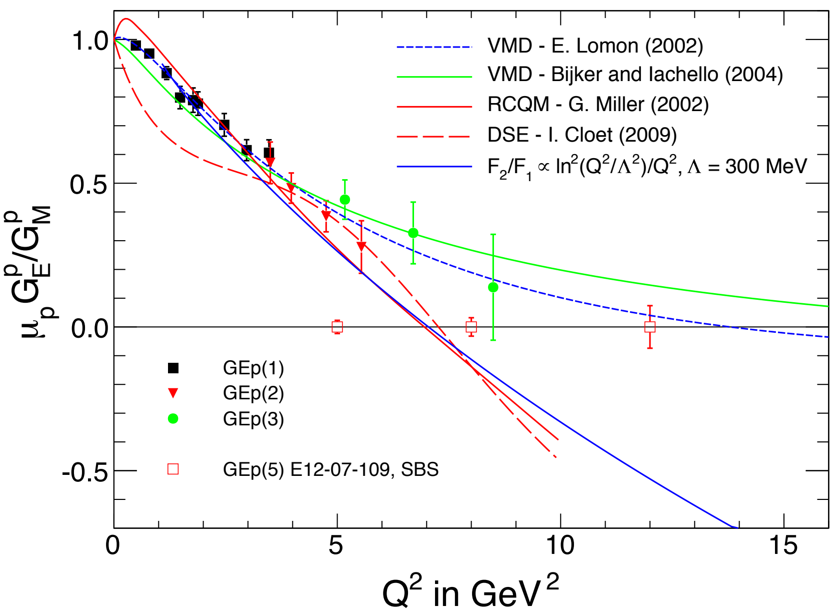

Figure 3: Shown are existing data and projected errors for measurements of the ratios of the electric and magnetic form factors of the proton. The projected errors for the measurements made with the Super Bigbite Spectrometer are indicated by the open red squares. Shown are the published results of GEp(1), GEp(2), GEp(3), and the projected results of GEp(5) in an approved 45-day run with the recommended highest value of momentum transfer 12 GeV^2.

The target will be based on the standard Hall A LH_2 cryotarget. A schematic representation of the experiment is shown in Fig. 4.

Proton form factors ratio, GEp(5) (E12-07-109)

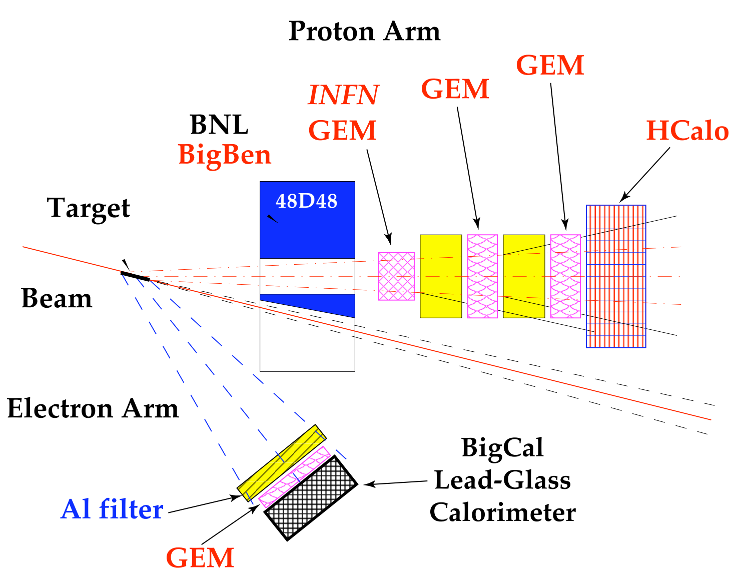

Figure 4: Shown is a schematic representation of the setup that will be used for GEp(5) (E12-07-109). The proton arm (set at a central scattering angle of 16.9°) incorporates a double polarimeter instrumented with GEM trackers and a highly segmented hadron calorimeter. The electron arm uses the existing "BigCal" electromagnetic calorimeter based on lead-glass.

GEp(5) will have excellent statistical power. For GEp(5), measurements will be made at three values of Q^2: 5, 8, and 12 GeV^2, while achieving an error in the ratio G_E^p/G_M^p of 0.07. The precision and reach of GEp(5) are illustrated in Fig. 3 in which we show results from GEp(1), GEp(2), and GEp(3), and the anticipated errors for GEp(5). The excellent precision that GEp(5) will obtain at 12 GeV^2 is clearly evident. Additional measurements at even higher values of Q^2 will be evaluated after SBS commissioning.

2.0.3 Precision Measurement of the Neutron Magnetic Form Factor up to Q^2 = 13.5 GeV^2

The Hall A GMn experiment was approved in January of 2009 by PAC34 to make measurements up to a Q^2 of 13.5 GeV^2(a request for two higher Q^2-points is also planned). It will determine G_M^n by a detailed comparison of the unpolarized elastic cross sections of the two processes $d(e,e'p)n$ and $d(e,e'n)p$. It will use essentially the same apparatus as GEn(2), with the exception that the target will be the Hall A liquid deuterium cryotarget. The schematic representation of the experimental setup was given above in Fig. 2.

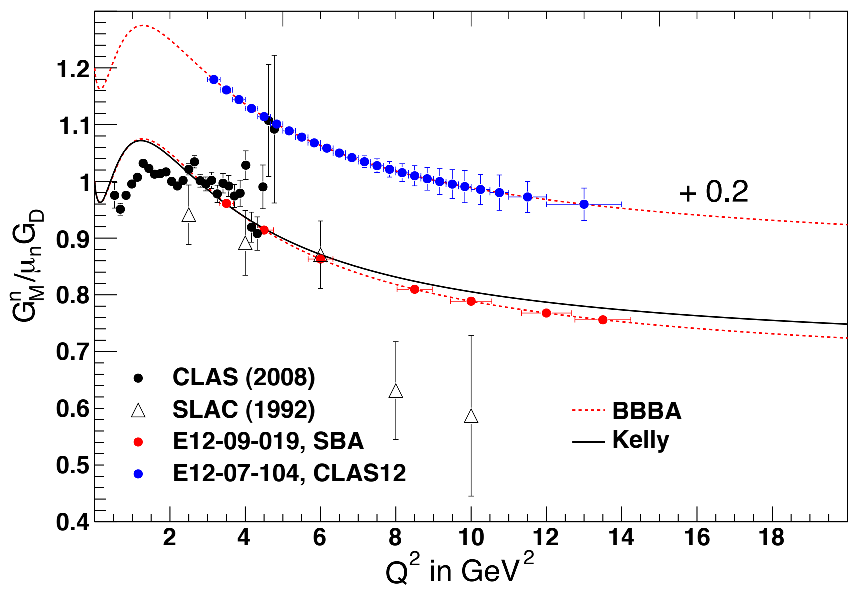

Figure 5: Published G_M^n data together with the projected statistical accuracy for Q^2-points of the CLAS12 G_M^n experiment (E12-07-104) in a 30-day run, and the projected statistical accuracy for Q^2-points of the Hall A G_M^n experiment (E12-09-019) in a 25-day run that will be performed using the Super Bigbite Spectrometer. The BBBA parametrization of the nucleon form factors was used to calculate of the projected statistics.

Like the other Super Bigbite Spectrometer form-factor measurements, the G_M^n measurement in Hall A will provide excellent accuracy and reach in Q^2, well beyond all competing efforts. Considering only the portion of the experiment that is fully approved, the GMn experiment will require only 25 days of running. The existing data for G_M^n, together with the projected errors for both the Hall A and the CLAS12 experiments, are shown in Fig. 5. While the magnetic form factor of the neutron has previously been measured up to 10 GeV^2, the few data that exist above 4.5 GeV^2 have uncertainties of about 10-20%. The GMn experiment in Hall A will provide sufficient accuracy to bring new understanding to this subject, including the aforementioned decomposition of the u- and d-quark distributions.

2.0.4 Additional experiments

In August 2011 PAC38 approved experiment E12-09-018, which will use the same spectrometer pair (BigBite and SBS) to study transversity effects in the process of semi-inclusive deep inelastic electron scattering from a polarized ^{3}He target. It will use the same equipment as the GEn experiment, but will require the refurbishment of an existing RICH counter (from HERMES) for particle identification in the hadron arm. Further experiments using SBS and BigBite are expected to be submitted to JLab PACs.

3 Milestones

The milestones in this document are research milestones that are derived from a technically feasible project time line. We will update those milestones as the project time line will be refined, especially by including a realistic funding profile.

Assuming approval by the DOE review committee in October 2011 the following project milestones are foreseen:

Table 1: Major Research Milestones of the SBS projects

Year, Quarter	Milestone Description
2013, Q2	GEM chamber pilot production started at UVa
2014, Q2	GEM tracker is ready for test in BigBite
2014, Q4	48D48 magnet tested in Hall A
2015, Q2	GEM tracker commissioning with beam
2015, Q3	SBS Basic Ready for Experiments
2016, Q1	SBS Neutron Form Factor Ready for Experiments
2017, Q2	SBS Proton Form Factor Ready for Experiments

A tentative plan of experiments in Hall A is a subject of ongoing analysis by the Hall A collaboration. Results of that analysis could change the schedule of experiments and years of the research milestones. The actual experimental schedule will be defined in the future, largely by the beam availability.

4 List of tasks

The following is a list of the research tasks only, it does not include DOE funded tasks for the construction of the SBS systems. The research tasks includes simulation and commissioning required for: Magnet, Beam line, GEM chambers, Lead-glass calorimeter, Hadron Calorimeter, Trigger, DAQ, and the analysis software. Some of the tasks involve more than one component. For example, the division between general software tasks and tasks related to an individual detector component is somewhat arbitrary.

5 Statement by the Hall A leader

The Hall A collaboration of over 70 user institutions has endorsed the research program of the SBS and will support the operation of the experiments. The core group of the electromagnetic form factor collaboration (EMFF) consists of about 30 physicists and has been one of the most active groups within the Hall A collaboration. After the completion of the SBS hardware, the SBS program will become a high priority for scheduling, consistent with the timeline and the milestones listed in this document as well as in the Project Management Plan. With the operation of SBS, the EMFF collaboration is expected to grow significantly.

6 Institutional Responsibilities

The tables list the responsibilities and the manpower available for the research tasks connected with the construction and operation of the SBS. We start with an overview detailing the responsibilities of all institutes and then list the responsibilities and tasks of the individuals. The manpower listed is sufficient to perform all the tasks listed in the task list. In addition to this manpower, the EMFF collaboration as a whole will be involved in the physics analysis of data derived from the SBS detector.

The core of the collaboration, Thomas Jefferson National Accelerator Facility, the University of Virginia, Carnegie Mellon University, the College of William and Mary, the University of Glasgow (Scotland), Norfolk State University, Rutgers the State University of New Jersey, the National Institute of Nuclear Physics (Italy), has recently successfully completed the E04-108 (GEp(3)) and E02-013 (GEn(1)) experiments at JLab.

The international part of the Super Bigbite collaboration plays a very important role in the project. It includes the groups from INFN (Italy) and Glasgow (Scotland). Efforts of the INFN group (Dr. E. Cisbani *et al.*) are concentrated on development of the GEM-based front tracker and associated electronics, for which INFN approved the full requested funding of 720k Euro. The Glasgow group (Hall-A Spokesperson Dr. J. Annand) is developing a front-end electronics for the large PMT arrays, which will be used in several Super Bigbite experiments.

Institutional Responsibilities

Table 2: Institutional Responsibilities

Jefferson Lab	Magnet Trigger & DAQ Coordination of the experiment preparation
W&M	Coordinate detector for the GEp(5) electron arm Physics/Lead-glass data analysis
CMU	Hadron calorimeter GEM tracker data analysis Physics/HCal data analysis
Glasgow	Development of the PMT front-end Time measurement Physics/Time-of-flight analysis
Rutgers	Trigger in GEp(5) FADC/FPGA data analysis Physics analysis
INFN/Rome	GEM module and GEM readout GEM simulation software Physics/GEM tracker data analysis
Catania	Front GEM module design & coordination Simulation of the GEM tracker GEM data analysis
UVa	Polarimeter GEM tracker design& coordination GEM modules for the coordinate detector GEM data analysis
NSU	Characterization of GEM front-end electronics Commissioning of GEM chamber DAQ Physics data analysis

Detailed Institutional Responsibilities

The tables below are based on the committed resources within the existing base grants from the funding agencies. Due to standard duration of these grants, its funding spans typically over next 3-4 years, somehow a bit short for the SBS projects. However, the commitments from spokespersons in the collaborative institutions are reaching at least over 2018. The committed manpower is sufficient to bring the SBS spectrometer to a stage of detector commissioning and readiness. According to many years practice the manpower required on the following stage (experiment running and analysis) will be easy to find within a wider Hall A collaboration. However, we expect that a core collaboration will be able to continue work.

Table 3: Jefferson Lab

	FTE $\times$ years
Staff	4.9
Post-doc	7

Table 4: College of William and Mary — Ch. Perdrisat's group

	FTE $\times$ years
Faculty	0.6
Post-doc	3
Student	1.5

Table 5: Carnegie Mellon University — Franklin/Quinn's group

	FTE $\times$ years
Faculty	2.8
Post-doc	5.6
Student	3.4

Table 6: University of Glasgow — Hall A Spokesperson: J. Annand

	FTE $\times$ years
Faculty	2.0
Staff	0.95
Post-doc	1.5
Student	0.75

Table 7: Rutgers University — R. Gilman's group

	FTE $\times$ years
Faculty	0.6
Post-doc	1.1
Student	1.1

Table 8: INFN/Rome — E. Gisbani's group

	FTE $\times$ years
Faculty	5.9
Staff	1.0
Student	4.2

Table 9: Catania University and INFN/Catania — E. Bellini's group

	FTE $\times$ years
Faculty	1.5
Staff	2.6
Post-doc	2.5
Student	2.7

Table 10: University of Virginia — G. Cates' group

	FTE $\times$ years
Faculty	1.05
Staff	1.5
Post-doc	2.5
Student	2.5

Table 11: University of Virginia — N. Liyanage's group

	FTE $\times$ years
Faculty	0.9
Post-doc	3.0
Student	7.5

Table 12: Norfolk State University — Khandaker/Punjabi's group

	FTE $\times$ years
Faculty	2.0
Post-doc	1.0
Student	4.0