Response to the Report from the DOE Review of the Heavy Photon Search Experiment on July 11, 2013
and
HPS Request for Formal JLab Approval

HPS Collaboration

March 14, 2014

Purposes of this Document

The Review of the HPS Experiment, which was organized by DOE HEP and which took place in Gaithersburg, Maryland on July 11, 2013, served two main purposes. First, it provided DOE HEP with an independent assessment of the HPS experiment in terms of the standard HEP merit review criteria as well as a critical review of the technical feasibility of the HPS design, construction plans, costs, schedule, manpower and resource availability, and staging plans for the experiment. Second, as was agreed prior to the review, it provided JLab management the information they required about the technical feasibility of the experiment and confirmation of the estimated background levels, before their granting HPS approval for physics runs in Hall B. This was necessary because the JLab PAC39 approved an HPS commissioning run, but had given the overall HPS experiment a “C1” rating, requiring a final approval from management prior to physics running.

Since the Review, DOE HEP has funded HPS, and work is already well-along in preparation for installation of the experiment in Hall B in the fall of 2014. With the receipt of the written Report of the Review from DOE HEP in mid-January of this year, HPS was instructed to provide DOE HEP a formal response within a year’s time which addresses the review committee’s suggestions and recommendations. In response to a specific request from HPS to move toward formal approval, JLab management asked that HPS document the actions it has taken in response to the DOE Review’s Recommendations and provide a detailed run plan for the 2015 “engineering” run and subsequent physics running in 2016-2019, along with specific reach projections.

This document responds to both these requests. It describes the actions HPS has taken to implement the recommendations from the review, and it addresses in detail comments and suggestions put forward by the reviewers and those summarized in the close of the review. This document is organized in four sections. The first will discuss how recommendations from the review have been implemented. The second addresses the comments that arose in the closeout at the time of the review. The third section addresses additional comments that appeared in the merit reviews. The concluding section presents the run plan requested by JLab management.

I. Implementation of Closeout Report Recommendations

1. Create (or maintain) a resource loaded schedule which includes the non-costed scientific time.

The original schedule was created by including only the engineering and technical manpower, which created the basis of the cost and schedule estimates for the project. A detailed list of the non-costed scientific manpower has now been completed and included in the schedule. The non-costed manpower has no impact on the costs and only a minimal impact on the original schedule, but its inclusion has led to a better understanding of scientific resources needed to complete the project on schedule. The list of scientific manpower has been assembled using information gathered in HPS sub-system reviews and direct talks with the project leaders and institute representatives. Minor changes have also been made in scheduling the engineering manpower, by leveling the scientific resources throughout the construction period of HPS, to avoid over-allocation. The resource-loaded schedule is actually maintained by the Project Manager, who updates the current status of the tasks at the periodical PM meetings. A copy of the revised schedule is attached as Appendix A; the non-costed scientific manpower is listed in Appendix B; costed engineering and technical manpower is listed in Appendix C.

2. Add "off-project" interface milestones related to JLab's 12 GeV schedule to the HPS schedule.

HPS, in conjunction with managers of the 12 GeV project and Hall B, has developed a list of "off project" milestones which have been added to the HPS Master schedule to account for activities at JLab. They include the beamline readiness in Hall-B, the commissioning of the RF separators, the refurbishing of the alcove, and the CLAS12 Torus installation. Several of these off-project milestones establish critical windows for HPS beamline and alcove installation prior to beam operations in Hall B, and drive the HPS beamline schedule. Two of the milestones, RF separator commissioning and CLAS12 Torus installation, are complex moving targets, but HPS will stay abreast of the future evolution of those schedules and work with JLab managers to interleave HPS installation , commissioning, and running.

3. Additional integration planning with TJNAF 12 GeV personnel relating to Hall B progress (regardless of the upstream/downstream decision) is crucial to HPS success. The HPS project team should clearly identify a technical coordinator to address these issues.

With the agreement of JLab management, HPS appointed Stepan Stepanyan to be the experiment's Technical Coordinator and liaison with the 12 GeV Project and Hall B in August of 2013. In this capacity, Stepanyan has held regular meetings with the Hall B lead engineer, Robert Miller, and the lead engineer of the CLAS12 Torus project, David Kashy. In addition he is holding regular meetings with the CEBAF Accelerator group to keep abreast of beamline schedules and accelerator plans. Recently, Stepanyan had two meetings with JLab management to review the scheduling of the engineering run and any potential conflicts for resources. Stepanyan reports to the HPS management team and Executive Board on these matters regularly, and also reports at the regular phone meeting with DOE HEP.

II. Addressing Comments from the Closeout Report

1. Closeout Report 5.4.2. HPS needs to fully analyze the test data and publish in peer-reviewed journals. This will help uncover possible problems. This is particularly true for the SVT alignment.

HPS agrees that fully analyzing the test data and publishing in peer-reviewed journals is both useful and necessary, and to this end has been preparing a paper summarizing the test run apparatus and its performance for publication in **NIM** or an equivalent journal.

Our alignment procedures are sound. After taking into account a detailed survey of sensor positions with respect to the support plates and the baseplate and the locations of the baseplate, support plates, and silicon modules on beamline, tracking residuals throughout most of the SVT are at the level of 50 microns or less. This experience also taught us the benefits of designing a more rigid support structure for HPS, including better survey targets on the apparatus, and allowing more time for in situ alignment. Since our tracking uncertainty is dominated by multiple Coulomb scattering, our present procedures are already very close to delivering the needed precision for the final alignment.

Even so, in order to remove alignment as a possible source of tracking uncertainty, we plan to use the Millepede-II alignment code. Millepede can solve for a given set of alignment constants based on one or more sets of input tracks. This program has been successfully used in the CMS inner detector alignment at the LHC and in other experiments. Our tracking software is already interfaced to Millepede-II and we are currently studying test misalignments in simulated events. We plan to use Millepede-II to further improve the alignment in the Test Run data.

2. Closeout Report 5.4.2. If you have 30k photoelectrons/GeV in the ECAL, is an APD upgrade going to help overall resolution?

HPS apologizes for the confusion at the time of the review regarding the expected signal size in the ECal's APDs. The answer given at the review was 30 photons/MeV, which is the light yield of our $PbWO_4$ crystals, not the photo-electron yield from the original APDs. When light collection efficiency and the quantum efficiency of these APDs is taken into account, 30 photons/MeV corresponds to about 2 photo-electrons/MeV (or ~2000 p.e./GeV). This yield resulted in a resolution of about 5%/√E(GeV) in the CLAS IC from which the crystals and APDs were taken. While the photo-electron yield may appear large, one should note that a 1 GeV electron impinging on the ECal deposits at most 70-80% of its energy in the crystals (sampling fraction), and that only about 60% of the deposited energy is deposited in a single crystal. For high energy showers 40%-50% of particle energy will be distributed among ~10 crystals. Threshold effects in crystals with lower energy deposits degrade the resolution. Boosting the photo-electron yield is needed to improve the energy resolution. With the new APDs, which have 4 times the area of the original APDs, the light yield will be ~8 p.e. /MeV. This will help not only to improve photo-electron statistics, but also to increase the signal compared to electronic noise, which in turn will allow lowering the energy readout threshold and thereby improve energy collection and position determination. Careful measurements made since the review have firmly established the photo-electron yield of the new APDS as 8000 p.e./GeV. With this light output, the ECal resolution is expected to improve by roughly a factor of two to 2.5%/√E(GeV). In addition, a lower energy threshold will make it possible to detect signals from cosmic ray muons which pass through the ECal crystals transversely. This will permit triggering the ECal on cosmic rays, and balancing the gains of all the different crystals throughout the ECal prior to data taking, thereby providing an ~ 10% energy calibration sufficient for HPS triggering on day-1 of data taking.

3. Closeout Report 5.4.2. The DAQ was only tested at 10% of the final expected rate. HPS should consider high-rate tests of the full system before the full run.

Since the Test run in 2012, the JLab part of the DAQ has been tested with event rates well above 50kHz on several different occasions, including beam tests at FNAL. The SVT part of the DAQ had not been designed to reach 50 kHz for the Test run. The front-end ASICs were limited to 21.5 kHz because of the operational mode, known buffering issues for the Ethernet transfers, and the 1 Gbit bandwidth to the JLab DAQ. All of these issues have been addressed in the design of the SVT DAQ for HPS. In order to avoid data rate limitations from the SVT DAQ, new firmware is being developed for the trigger interface board to allow distributing data readout over several processors in the SVT DAQ crates. This change will be ready in May 2014 when testing with the complete system will start. The SVT DAQ rate testing is staged. The data flow and event building is first exercised on stand-alone development boards and then tested with data from more and more hybrids until the system hardware is fully available. A complete setup of the JLab DAQ will be operated at SLAC for final integration and to allow full system rate tests.

Below is a breakdown of the testing plan, in chronological order:

- Use updated firmware on the new front-end board to operate the APV25 ASIC in burst trigger mode (overlapping trigger and readout) up to the theoretical maximum of 50kHz.
- Test the SVT trigger rate capability in a single RCE using an existing development board without real sensors. This will utilize the JLab CODA software and RCE firmware, just like actual running. Test firmware is used to generate fake data corresponding to the occupancy we expect in the detector and software triggers are used to test high event rates.
- As RCE platform hardware is becoming available, we will transition to the actual RCE platform and run high rate tests with multiple RCE's corresponding to up to half the expected data from the SVT. This exploits the same firmware to generate simulated data and software triggers as in the previous step.
- The updated SVT trigger interface is tested by running CODA with a JLab trigger supervisor based on the hardware and software that will be used in the actual experiment. It will generate random high rate external triggers to the SVT. Fake SVT data will be generated to allow testing without real detector modules.
- While the JLab DAQ has already been tested to higher rates than needed for HPS, the JLab DAQ will be exercised by operating the FADC boards in raw mode. This allows testing both rate capability and bandwidth by changing event size and external trigger rates independently.
- Final high rate tests of the SVT DAQ system at SLAC will use the real detector modules with triggers sent through the JLab CODA trigger supervisor. By adjusting signal thresholds appropriately, we can generate the occupancies we expect in real running.
- Integration of the combined system, before beam is available, is done by operating the FADC boards in raw mode and the SVT DAQ with adjusted thresholds, as explained above.

4. Closeout Report 5.4.3. Online software development should continue so that they are able to quickly monitor and analyze data online during data taking. They could add a monitoring stream to the DAQ, for example.

The HPS DAQ already provided a system for tapping into the live data stream, called the Event Transport Ring (ET), at the time of the Test Run. HPS used this system to analyze events and display histograms. This tool is being improved so that it will also function as a single event display. The histograms and underlying analysis needed for this tool to provide effective real time monitoring of detector performance are being refined and further developed by the detector subgroups. Online monitoring was available in the Test Run; improved online monitoring will be available for HPS runs in the future.

5. Closeout Report 5.4.3. A mock data challenge before running would be useful.

As a result of the suggestions from the review, the collaboration has decided to conduct a mock data challenge (MDC). The goals of the MDC are twofold: demonstrate that we are able to process data and generate simulation needed once data arrives and to perform a complete, nominal data analysis in order to publish results in a timely manner.

The MDC will allow us to exercise our simulation production and reconstruction framework in advance of data taking and verify that the computing resources provided by JLab are adequate. We are in the process of automating the job submission processes for all of the steps (event generation, simulation, reconstruction, and bookkeeping) at JLab. We plan to start full scale production for the MDC in early March.

In addition, we are currently organizing groups to work on different aspects of the data analysis. We will have analysts working on different methods of cut optimization, signal extraction, limit setting and systematic error determination for both the bump-hunt and vertexing A’ searches. Groups are also working on improving the reconstruction (e.g. adding information from the recoil electron when it is within the acceptance and exploiting the improved Ecal resolution to better the momentum resolution) in an effort to improve the reach of HPS. All of these efforts will go a long way toward having a robust data analysis technique in time for the first data and will hopefully allow for a quick turnaround to publication.

6. Closeout Report 5.4.3. Consider techniques, like using extra targets and off-axis beam, to assist with aligning the SVT which will be crucial for needed vertex resolution.

HPS needs a variety of runs to finalize SVT alignment even after all the survey data have been taken into account, in particular to determine the relative alignment between the upper and lower SVT halves using tracks *in the data.* To do so, we are planning to take data with an additional target upstream of the regular target and may also use carbon and CH_2 targets to study elastic ep scattering. In order to remove possible transverse offsets related to constant curvature (parabolic in z) we will take data with a gold target about 3m upstream and without magnetic field. Since our tracking and vertex resolution is dominated by multiple scattering, the alignment precision need not be at the level of the intrinsic 6 μm spatial resolution, but must still be well below the multiple scattering errors (~100 μm) to minimize systematics.

7. Closeout Report 5.4.3. Offline software for the muon system was discussed, but muon ID using the ECAL might be a higher priority.

While the ECAL is an excellent calorimeter, it is not expected to have sufficient discriminatory power to identify muons by itself, or perhaps more critically, to trigger on muons. Such a trigger in the ECal would need to correlate MIP-level ECal clusters with high associated track momentum, but the latter is not available at trigger level. A dedicated muon detector, however, could properly trigger on muons and confirm particle ID offline. Such a muon detector has been part of the overall HPS concept, but is as yet unfunded, and likely would not be of use in the 2015 running cycle because only low beam energies are anticipated.

8. Comments concerning schedule, budget, and project management.

(a) Closeout Report 5.4.3 The collaboration should consider adding additional design reviews for the ECAL, DAQ, etc.

A detailed plan of design reviews for each sub-system has been implemented and completed. A standard format was adopted, reviewing the technical status of the project, schedule, budget, manpower, risks, and interfaces. The reviews were chaired ex-officio by the Project Manager and the two Project Scientists. The sub-system project leader organized presentations. From two to four external reviewers were invited to participate in order to get unbiased comments and recommendations. In chronological order the reviews of the following sub-systems have been held: ECal, SVT&DAQ, Slow Control, Beamline, Software, and TDAQ. The agenda with the talks and the final reports are available here:

https://confluence.slac.stanford.edu/display/hpsg/Reviews.

(b) Closeout Report 5.4.4. A schedule which showed both hours and durations by task would have been most helpful in assessing the appropriateness of resources.

The master schedule is managed with MS Project in which the individual tasks are described by start-finish-duration-predecessors. With the aim of simplifying the representation of a complex schedule, it was decided to suppress this level of detail in the proposal, but all of the information is of course available. The current version is shown in Appendix A.

(c) Closeout Report 5.4.5. Schedule slack is not specifically identified within task lines, which makes it difficult to assess overall schedule contingency.

Clearly one of the major challenges for HPS is the tight schedule, constrained by the early physics opportunity at JLab in October 2014, which has allowed less than 18 months for construction. Although the technical challenges are not big, the float in the schedule for the individual sub systems is rather small, of the order of 4-6 weeks. While these float periods are visible in the individual subproject schedules, the master schedule, which was presented at the review, is sufficiently complex that this level of detail was not included. The Project Manager reviews the individual schedules and schedule float by internally monitoring the status and schedules of each of the sub-projects.

(d) Closeout Report 5.4.5. It may be informative to make a copy of the schedule and perform a "what if" analysis, removing float from tasks and determining the earliest possible finish date.

This is indeed a valuable exercise, which we started to implement during the review process. At each review we collected information about the leveled manpower, expected risks and mitigation procedures, and projected all of them into an updated schedule. The latest release of the master schedule reflects these factors, which set the installation readiness about 4 weeks before the expected date. Beside the specific HPS tasks we have to deal also with "off-project" constraints like the CLAS12 and 12 GeV upgrade schedules. The milestones that may have the largest impact on the HPS schedule are the start of the torus installation of CLAS12 in June 2014 and the readiness of the RF separators in October 2014. We monitor both of them regularly but of course we have no direct control over either. A "what-if" analysis applied to these external milestones leads us to think that a delay in the torus installation will not impact HPS negatively, but a delay in the readiness of the RF separators would delay HPS commissioning and perhaps running. On the other hand, if they are significantly ahead of schedule, problems would arise for HPS, but this is considered very unlikely. Of course, we are aware that a "what-if" exercise is an ongoing process and that is why we will repeat it throughout the duration of the project, with the aim to steer around any schedule changes that arise.

(e) Closeout Report 5.4.5. A critical path analysis was not presented. It would be very helpful for reviewing and managing the project.

In fact, much of the critical path has been identified, although it was not called out explicitly in the presentations at the review. The HPS critical path is set by the delivery by Hamamatsu of the APDs in early March; the refurbishment of the alcove in June, before the magnet installation work of CLAS12 starts; the SVT&DAQ full system test in July at SLAC; and the readiness of the SVT and ECal and the availability of Hall B for HPS installation in September.

(f) Closeout Report 5.4.6. A detailed staging schedule was not shown for either upstream or downstream option.

Staging HPS at JLab begins with refurbishing the alcove with all the infrastructures (magnets, girders, supports, beam pipes, services, etc.) required. The girders and the magnet are on the critical path due to the CLAS12 torus installation constraint, while the services can be installed later. The ECal will be assembled at JLab in May, where it will be tested and commissioned with cosmic ray muons by the end of August. The SVT will be shipped to JLab by the end of July and re-assembled and tested in a clean room there before moving it onto the beamline. Other subsystems like the Slow Control, the TDAQ and the Software will be staged independently and in parallel, with low impact on the Hall-B schedule. Once the SVT and ECal are installed on the beamline, a crosscheck of all the functionalities is expected to take about one week. Many of these tasks are already described in the current schedule. The endgame installation will require close coordination with the Hall-B personnel. Detailed plans for the final installation steps are under discussion and they will be developed fully a few months before work commences.

(g) Closeout Report 5.4.6. No ES&H milestones or reviews were mentioned.

Construction of detector components is proceeding at different laboratories (SLAC, JLab, IPN-Orsay and INFN). Each sub-group is following the ES&H guidance of its respective institutions. Jefferson Lab has established procedures (now being updated) for an experiment readiness review that will include safety assessment of the detector installation and beam running. Experiments provide information to produce experimental safety assessment and radiation safety documents, which are reviewed and must be approved by management. HPS will work closely with the JLab Physics Division Safety Office to conduct experiment readiness reviews, and prepare HPS operating procedures for approval.

III. Addressing Additional Comments from the Merit Reviews

1. Section 3.2, Reviewer 3: “One particular item in these test run results sticks out to me though. The SVT was surveyed, but not aligned with tracks. The explanations that go along with Figure 50 in the proposal state that extrapolated track position resolutions at the HPS target at 10 cm upstream need to be about 100 microns. If I understand Figure 50 and the intrinsic resolutions correctly, it looks to me that this resolution will be about 300 microns, not 100 microns.”

In fact, tracks have been used in aligning the SVT, and sensor positions have been adjusted to reduce the measured residuals. Extrapolated tracks have also been used to align the top and bottom plates which support all the sensors by requiring that they meet at the converter target position at the known height of the beam.

The extrapolated track position resolutions result from the track extrapolation uncertainty in quadrature with the multiple coulomb scattering uncertainty which arises in the first layers of the tracker. The multiple scattering errors dominate. The distance to the conversion target in the Test Run (67 cm) is significantly greater than that to the nominal electron target in HPS (10 cm), so the measured resolution at the conversion target is very much worse than that expected for normal electron running. In Figure 1 we compare the vertical (y) component of the extrapolated track resolution in the Test run geometry (on the left) to that in the electron run geometry (on the right). Note that the resolution is roughly a factor 8 worse in the Test Run geometry, most of which (factor 7) is just the larger contribution of the multiple Coulomb scattering uncertainty to the more distant target.

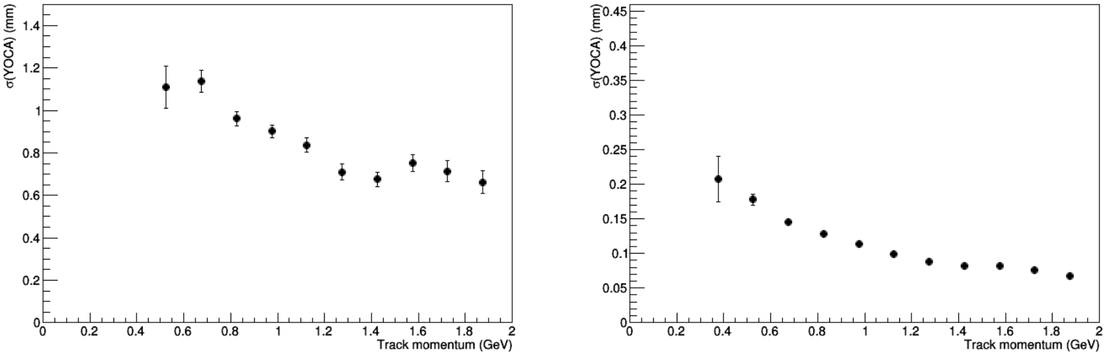


Figure 1. Vertical (Y) component of the extrapolated track resolution in the Test run (left) and in the electron run (right) geometry.

The Test Run resolution shown in Fig. 50 in the proposal is about 1 mm, averaged over a range of momenta, in fair agreement with the calculation above, and with the full simulation MC prediction given in the proposal. The calculation above shows that the corresponding resolution for the electron run geometry is in the range of 100 microns, as claimed. The full simulation also verifies our simulation of the z-vertex distributions, and as also shown in Fig. 50, the extrapolated track resolution in x.

It is important to remember that in the Test run, as well as in electron running, the dominating source of uncertainty in the tracking and vertexing is multiple Coulomb scattering. The fact that relatively good agreement between data and simulation is obtained means that we have a good understanding of our material distribution and budget in the SVT.

2. Section 3.2 Reviewer 2: There are aspects of the silicon readout that will eventually need to operate in the vacuum but were not tested in this run. My guess is that the performance of those components in vacuum, near the beam, in the magnet, is probably now one of the larger technical risks."

Reviewer 2 is correct in assuming that some elements of the revised SVT DAQ were not tested in the Test Run for operation in vacuum. However, we are qualifying all materials to be used in the new SVT Front-End boards for vacuum and magnetic field compatibility, just as we had qualified relevant materials for the Test Run. We are doing the same for new flex cables and other cabling that will be used in vacuum, and for the flange boards that connect the front end boards to the outside environment. We will also qualify the final boards for vacuum compatibility and operate them in magnetic fields of the same magnitude and direction as expected during running. In addition, we have calculated the radiation load on the electronics and have taken appropriate steps to minimize any risk for short term upsets and long term damage. In the event of a radiation accident beyond our control, the SVT support structures are being designed to allow us to swap SVT Front-End boards without having to fully extract the detector from the analyzing magnet.

3. Section 3.3 Reviewer 4: …I note a lot of tasks that are in parallel, especially in the electronics and DAQ sections which makes me nervous, given the size of the collaboration and the other activities of many of the members."

The schedule is full, as noted by Reviewer 4. However, we have prepared a detailed resource-loaded schedule outlining the tasks and associated manpower which accounts for their time available to HPS and their commitments elsewhere. Adequate resources are available. While the schedule is busy, care has been taken to ensure that there is enough time to complete tasks. Details are provided in the resource loaded schedules attached in the appendices.

4. Additional comments raised in the Summary of Merit Reviews

Here we address some remaining comments made in Section 3 of the Report from the Review of the SLAC/JLab Heavy Photon Search Experiment covering a variety of subjects.

In 3.1, Reviewer 3 opines that Hall A might have been a better location for HPS. Hall B was chosen to take advantage of early running available in Hall B, to make use of the Hall B FADC, trigger, and DAQ technologies already built into our designs since the Test Run, to exploit Hall B beam instrumentation and expertise with currents in the range needed by HPS, and keep costs to a minimum, since estimates for moving to Hall A were prohibitive. In addition, Hall A would also present HPS with competition from other experiments. Hall B was the right choice and this is a very done deal.

In 3.2, reviewer 4 notes that the flux encountered in the Test Run was many orders of magnitude lower than that to be encountered in the experiment proper. This is simply true. The photon beam running allowed us to confirm expectations for backgrounds in electron beam running, but did not test the capability of the detectors to stand up to the expected charged particle rates. Reviewer 5 in the same section questions why there is dead time in the FADC. In fact, the preamps are directly coupled to the input of the FADC, so the entire pulse shape is continuously recorded sans dead time. However, dead time can still occur if there are many triggers with a short time (extremely unlikely), since the time to record and transfer one event after another can exceed the buffer length for the FADC information. Dead times are expected to be well below 1% and will be measured.

In 3.3, Reviewer 4 questions the importance of adhering to the proposed schedule, which is somewhat aggressive, lacking a description of what competing experiments will do. HPS needs to meet this aggressive schedule to secure beam time in Hall B before the CLAS12 detector installs and commissions, which will require a year or more. As is, HPS must interleave its running with CLAS12 toroid magnet installation and test, but this is workable. Since several experiments are working to close off the available g-2 parameter space, and the group at Mainz plans to attack the same vertex region HPS will explore, it behooves HPS to be timely.

Finally, in 3.5, Reviewer 3 asks for further discussion on risk mitigation in our present commissioning plans. This is addressed somewhat in II 8 (f) above. The essence of our risk mitigation is to remain in constant communication with the Hall B beam line and toroid installation projects, and maintain a presence at their scheduling meetings, so we can work with them to preserve our running time. Our Technical Coordinator, stationed at JLab, is doing this.

IV. HPS Run Plan

HPS is requesting an engineering run in FY2015, physics running in 2017, and additional physics running in 2019 and beyond. By agreement with JLab management, HPS is hereby requesting approval for the 2015 engineering run, which is detailed below along with estimates of its experimental reach. Additional running in 2015, 2017, and 2019 and beyond is also outlined along with corresponding reach estimates. By agreement, formal laboratory approval for the additional running will be considered after the demonstration of successful data taking in 2015. The running in 2017 will complete the first round of our HPS search; running in 2019 and beyond will bolster and extend that first round and search for True Muonium, using the balance of the 180 days of running requested of PAC 37 in our original proposal.

The run plan given below will cover new, large, and well-motivated regions of heavy photon coupling-mass parameter space. This is true despite the fact that many new results from a number of experiments have been presented since the time of the original HPS proposal. The present state of published heavy photon searches is shown in Figure 2. It includes new

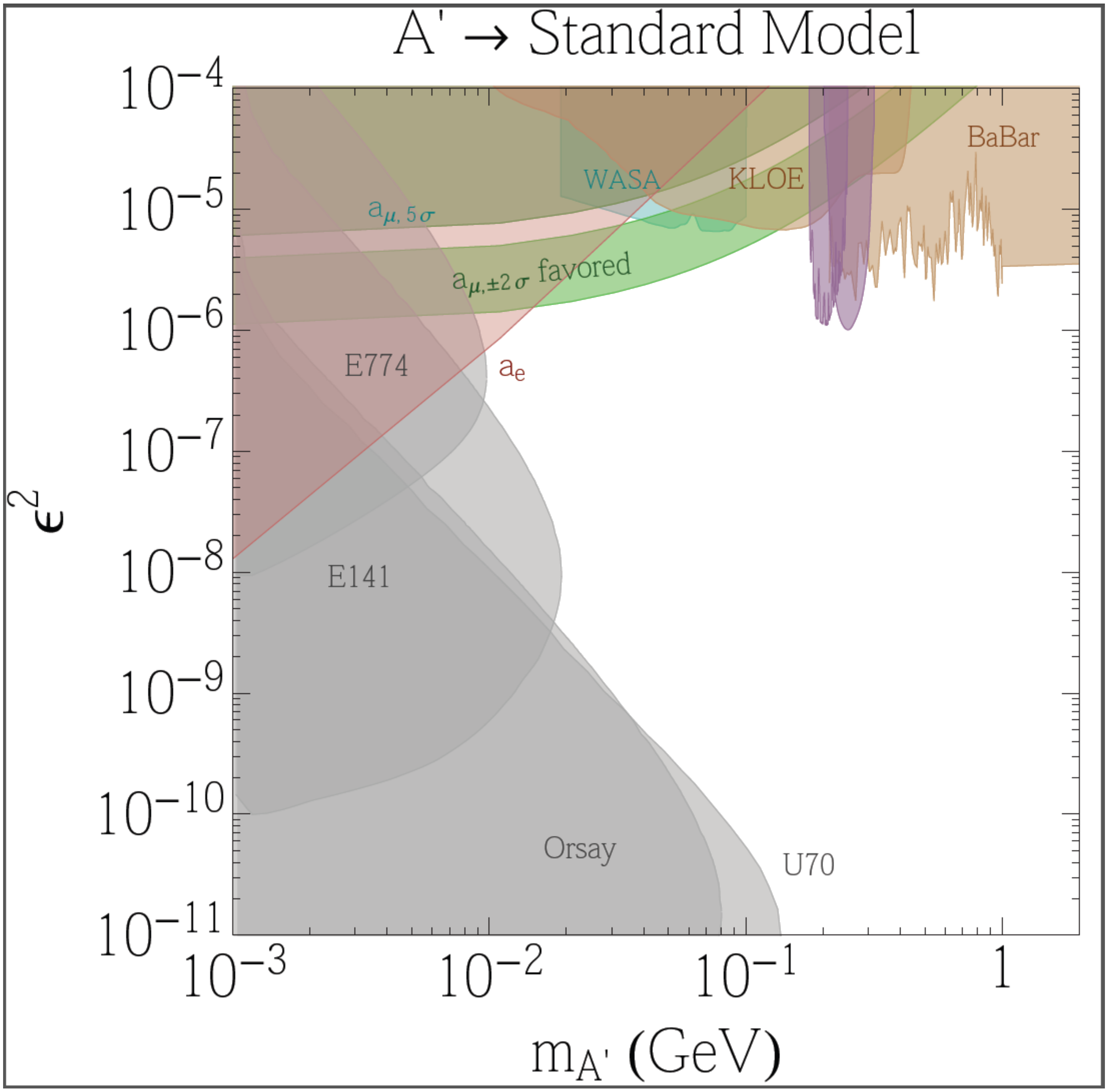


Figure 2. The present state of published heavy photon searches.

results from KLOE and WASA. Preliminary results from BABAR and PHENIX (not shown) exclude most of the region above $\varepsilon^2 > 10^{-6}$ except for some of the muon g-2 "preferred" region below $m_{A'} < 50$ MeV, leaving HPS one final target for low energy bump hunting. Almost all of the HPS "vertex search" region is unexplored.

Our run plan is given below. Times are given in weeks of PAC time, i.e. beam delivered on target time. Time on the floor is expected to be 2× the beam time estimates for running in physics run periods, but considerably longer (4×?) during the engineering run because it is confined to nights and weekends.

Engineering run in FY2015, total of 3 weeks of beam time.

- 1 week of detector commissioning at 2.2 GeV
- 1 week of data taking at 2.2 GeV (250 nA on 0.125% X_0 W target)
- 1 week of data taking at 1.1 GeV (50 nA on 0.125% X_0 W target)

This run constitutes the first HPS physics run. It will cover appreciable new parameter space in both the bump hunt and the vertexing regions and will lead to our first physics results. Commissioning and running begin at 2.2 GeV to maximize compatibility with the CEBAF 12 GeV program and other experiments. Running at 1.1 GeV is needed to cover the remaining g-2 preferred region. (Note that the bump hunt reach in the figure below is somewhat less than in our previous estimates. A re-evaluation of trident backgrounds resulted in lowered significance in the bump hunt region. The change in the vertex region is practically negligible.)

Additional Running in FY2015 if time is available, totaling 2 weeks of beam time.

- 2 weeks of data taking 4.4 GeV (350 nA on 0.25% X_0 W target)

If HPS demonstrates successful data taking in the engineering run, and if additional time can be found in the Spring 2015 running or in Physics Period I, then the coverage of A' parameter space can be markedly improved with an additional run at 4.4 GeV. The reach of the engineering run and this additional running is shown in yellow in Figure 3. The solid curves show the 2 sigma limits, the dashed curves the 4.5 sigma limits as discussed below. Two weeks of running at 4.4 GeV is also expected to produce 0.4 detected True Muonium events, decaying in the region between 1.2 and 5.0 cm downstream of the HPS target, which gives HPS the opportunity to sight TM for the first time. Genuine discovery must await more statistics.

Physics Run in 2017, total of 7 weeks of beam time.

- 2 weeks of data taking at 2.2 GeV (250 nA on 0.125% X_0 W target)
- 2 weeks of data taking at 4.4 GeV (350 nA on 0.25% X_0 W target)
- 3 weeks of data taking at 6.6 GeV (450 nA on 0.25% X_0 W target)

With this additional running at 2.2 and 4.4 GeV, and new running at 6.6 GeV, HPS will extend its reach in the vertexing and bump hunt regions to the point where any heavy photon signal within a large region of phase space will 1) be seen with high probability; and 2) if seen, will very unlikely be due to a background fluctuation. These conditions are satisfied if the search significance is ≥ 4.5 sigma, and as shown in Figure 4, this will be the case for a large region of parameter space after the 2015 and 2017 running. Again, the yellow curves show the reach of the 2015 running, and the blue regions the reach of the combined 2015 and 2017 running. Solid curves show 2 sigma limits, and dashed curves 4.5 sigma limits. The energies listed need not be provided exactly; energies close to those listed (say ± 10%) will be acceptable. Three-week runs at each energy mark a reasonable threshold for the HPS experiment in the vertex region: three weeks is adequate to secure a good fraction of the total parameter space accessible to the experiment. Beyond about three weeks, the gains in coverage accrue very slowly. In the bump hunt region, the sensitivity increases with the square root of run time, so even a factor of two increase in coverage takes four times the accumulated run time. The running at 6.6 GeV allows HPS to extend its coverage to masses above 200 MeV in the vertex region, and to much higher masses in the bump hunt region. In addition, with a total of 3 weeks of data at both 4.4 and 6.6 GeV, the total expected yield (after cuts) for the true muonium 1 $^3S_1$ state is 2.0 events, in the decay region 1.2 to 5.0 cm. This rate does not guarantee TM discovery, but it does not exclude it either and makes a "sighting" fairly probable.

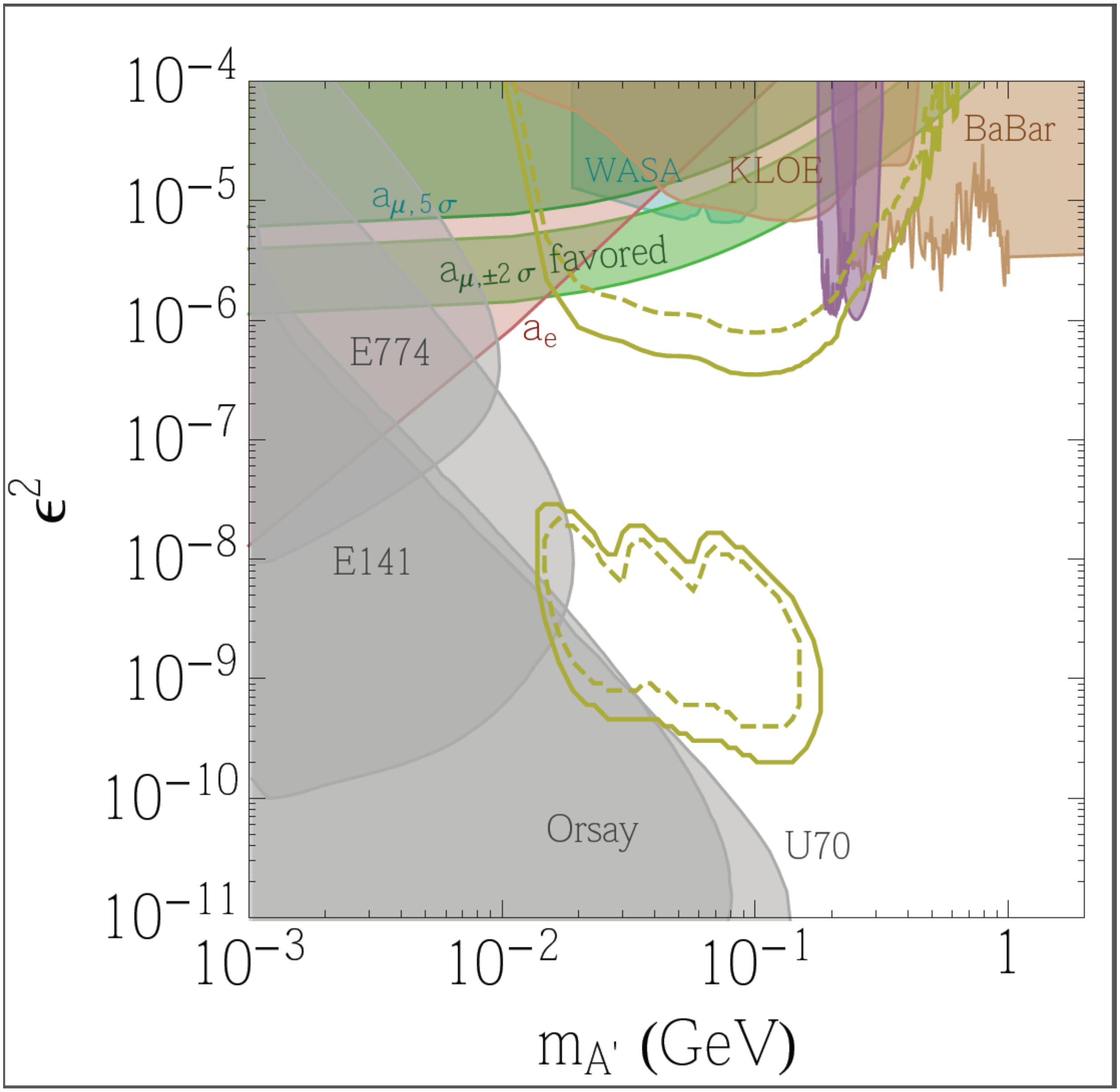


Figure 3. The reach of the engineering run and the additional running of 2 weeks at 4.4 GeV. The solid curves show the 2 sigma limits, the dashed curves the 4.5 sigma limits.

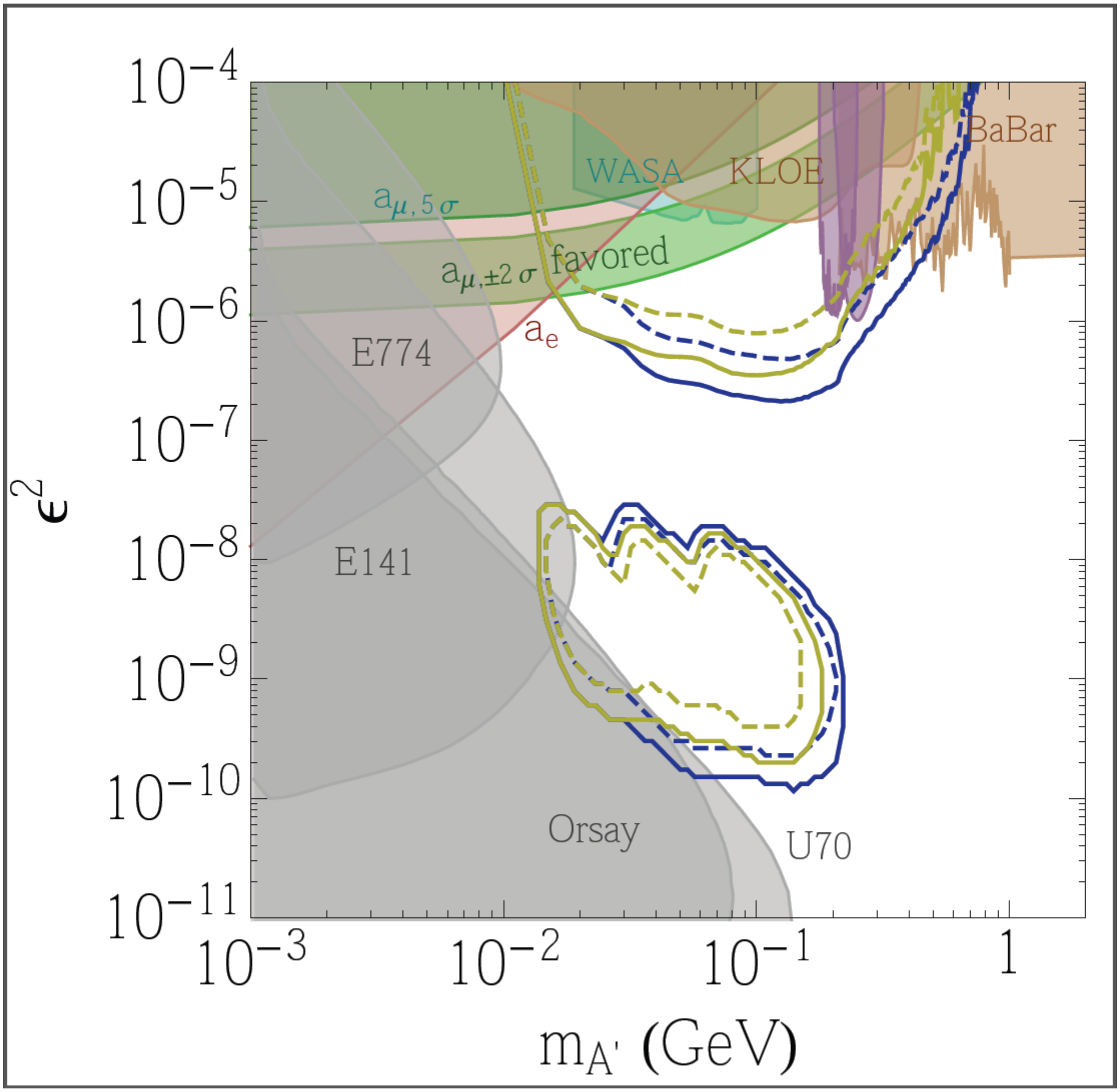


Figure 4. The combined reach of the engineering run, the additional running of 2 weeks at 4.4 GeV, and the proposed running in 2017 are shown in blue, the combined 2015 running in yellow. The solid curves show the 2 sigma limits, the dashed curves the 4.5 sigma limits.

Physics Run in 2019 and beyond, total of 15 weeks of beam time.

- 6 weeks data taking at energies TBD
- 9 weeks data taking at 6.6 GeV

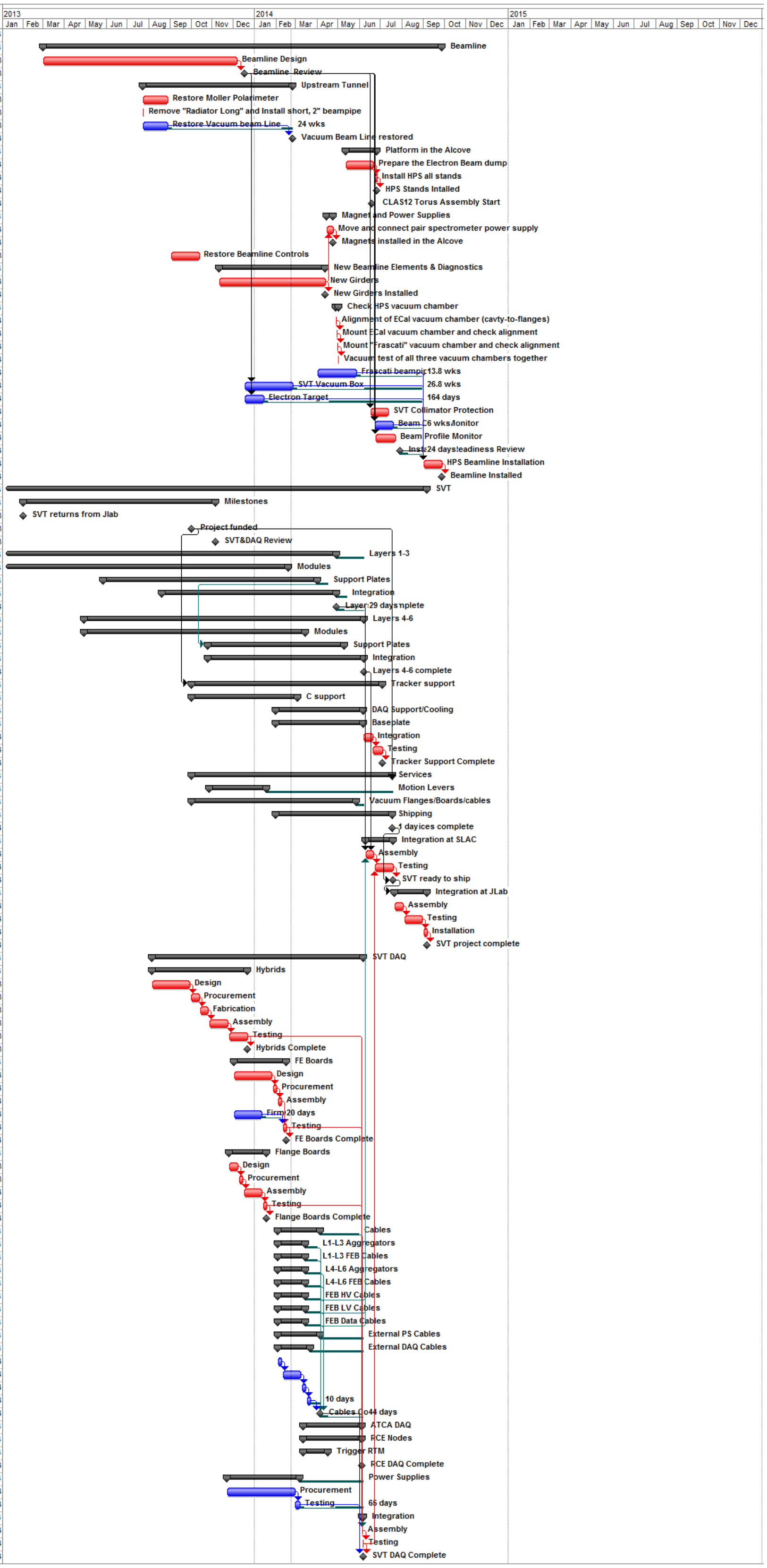
Clearly the HPS Run Plan in 2019 and beyond will be impacted by the actual performance of the experiment as demonstrated in the 2015 and 2017 runs, the state of world-wide searches for heavy photons and other light dark sector particles, and further studies of True Muonium. The actual HPS performance certainly depends upon the maximum currents at which we can take good data; it also is subject to possible improvements coming from the use of the good energy resolution of the ECal to improve invariant mass resolution, and possible reductions in backgrounds achievable when the recoil electron is detected. HPS performance may significantly improve in time. True Muonium detection will be enhanced with special purpose targets.

The 6 weeks of data taking at a variety of energies will be used to maximize HPS coverage of A' parameter space, selecting energies as appropriate. If performance gains are realized, the bump hunt region could be improved significantly.

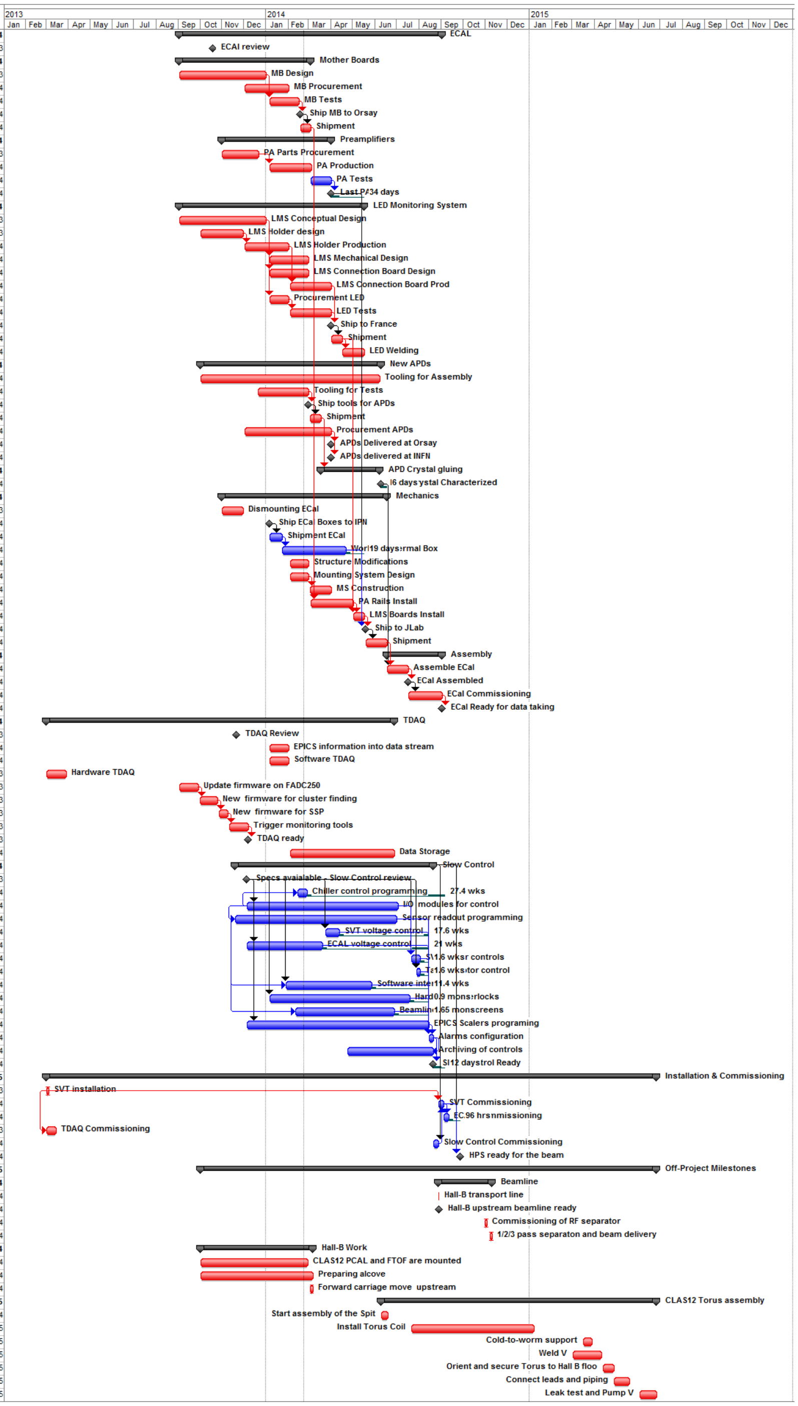
The 9 weeks of data taking at 6.6 GeV will both guarantee full coverage of HPS parameter space at the highest accessible masses, and, with the addition of multiple targets, provide the chance to boost the TM yield/run time by a factor ~3. This running could provide a total TM signal of ~12 or more events, certainly adequate for the unambiguous discovery of true muonium and the first estimates of its production cross section and lifetime.

Appendix A Resource Loaded Schedule

ID	Task Name	Leveling Delay	Duration	Start	Finish
1	**HPS**	**0 edays**	**.13 days?**	**Mon 1/7/13**	**Thu 8/25/16**
2	**Beamline**	**0 edays**	**401 days**	**Fri 3/1/13**	**Fri 9/26/14**
3	Beamline Design	0 edays	10 mons	Fri 3/1/13	Thu 12/5/13
4	Beamline Review	0 edays	1 day	Mon 12/16/13	Mon 12/16/13
5	**Upstream Tunnel**	**0 edays**	**145 days**	**Tue 7/23/13**	**Mon 2/24/14**
6	Restore Moller Polarimeter	0 edays	5 wks	Tue 7/23/13	Mon 8/26/13
7	Remove "Radiator Long" and Install short, 2" b	0 edays	1 day	Tue 7/23/13	Tue 7/23/13
8	Restore Vacuum beam Line	0 edays	5 wks	Tue 7/23/13	Mon 8/26/13
9	Vacuum Beam Line restored	0 edays	0 days	Mon 2/24/14	Mon 2/24/14
10	**Platform in the Alcove**	**0 edays**	**32.5 days**	**Mon 5/12/14**	**Wed 6/25/14**
11	Prepare the Electron Beam dump	0 edays	6 wks	Mon 5/12/14	Fri 6/20/14
12	Install HPS all stands	0 edays	0.5 wks	Mon 6/23/14	Wed 6/25/14
13	HPS Stands Intalled	0 edays	0 days	Wed 6/25/14	Wed 6/25/14
14	CLAS12 Torus Assembly Start	0 edays	0 days	Wed 6/18/14	Wed 6/18/14
15	**Magnet and Power Supplies**	**0 edays**	**7.5 days**	**Mon 4/14/14**	**Wed 4/23/14**
16	Move and connect pair spectrometer power s	0 edays	7.5 days	Mon 4/14/14	Wed 4/23/14
17	Magnets installed in the Alcove	0 edays	0 days	Wed 4/23/14	Wed 4/23/14
18	Restore Beamline Controls	0 edays	6 wks	Mon 9/2/13	Fri 10/11/13
19	**New Beamline Elements & Diagnostics**	**0 edays**	**100 days**	**Mon 11/11/13**	**Fri 4/11/14**
20	New Girders	0 edays	20 wks	Mon 11/11/13	Fri 4/11/14
21	New Girders Installed	0 edays	0 days	Fri 4/11/14	Fri 4/11/14
22	**Check HPS vacuum chamber**	**0 edays**	**4 days**	**Mon 4/28/14**	**Thu 5/1/14**
23	Alignment of ECal vacuum chamber (cavty-to-	0 edays	1 day	Mon 4/28/14	Mon 4/28/14
24	Mount ECal vacuum chamber and check align	0 edays	1 day	Tue 4/29/14	Tue 4/29/14
25	Mount "Frascati" vacuum chamber and check	0 edays	1 day	Wed 4/30/14	Wed 4/30/14
26	Vacuum test of all three vacuum chambers to	0 edays	1 day	Thu 5/1/14	Thu 5/1/14
27	Frascati beampipe 1	0 edays	8 wks	Tue 4/1/14	Mon 5/26/14
28	SVT Vacuum Box	0 edays	8 wks	Tue 12/17/13	Mon 2/24/14
29	Electron Target	0 edays	10 days	Tue 12/17/13	Mon 1/13/14
30	SVT Collimator Protection	0 edays	4 wks	Mon 6/16/14	Fri 7/11/14
31	Beam Offset Monitor	0 edays	4 wks	Mon 6/23/14	Fri 7/18/14
32	Beam Profile Monitor	0 edays	4 wks	Tue 6/24/14	Mon 7/21/14
33	Installation Readiness Review	0 edays	1 day	Mon 7/28/14	Mon 7/28/14
34	HPS Beamline Installation	0 edays	4 wks	Mon 9/1/14	Fri 9/26/14
35	Beamline Installed	0 edays	0 days	Fri 9/26/14	Fri 9/26/14
36	**SVT**	**0 edays**	**425 days**	**Mon 1/7/13**	**Fri 9/5/14**
37	**Milestones**	**0 edays**	**198 days**	**Fri 2/1/13**	**Tue 11/5/13**
38	SVT returns from Jlab	0 edays	0 days	Fri 2/1/13	Fri 2/1/13
39	Project funded	0 edays	0 days	Tue 10/1/13	Tue 10/1/13
40	SVT&DAQ Review	0 edays	1 day	Tue 11/5/13	Tue 11/5/13
41	**Layers 1-3**	**0 edays**	**331 days**	**Mon 1/7/13**	**Mon 4/28/14**
42	**Modules**	**0 edays**	**281 days**	**Mon 1/7/13**	**Mon 2/17/14**
69	**Support Plates**	**0 edays**	**211 days**	**Mon 5/27/13**	**Mon 3/31/14**
82	**Integration**	**0 edays**	**171 days**	**Mon 8/19/13**	**Mon 4/28/14**
93	Layers 1-3 complete	0 edays	0 days	Mon 4/28/14	Mon 4/28/14
94	**Layers 4-6**	**0 edays**	**280 days**	**Mon 4/29/13**	**Fri 6/6/14**
95	**Modules**	**0 edays**	**220 days**	**Mon 4/29/13**	**Fri 3/14/14**
148	**Support Plates**	**0 edays**	**131 days**	**Fri 10/25/13**	**Fri 5/9/14**
161	**Integration**	**0 edays**	**151 days**	**Fri 10/25/13**	**Fri 6/6/14**
172	Layers 4-6 complete	0 edays	0 days	Fri 6/6/14	Fri 6/6/14
173	**Tracker support**	**0 edays**	**188 days**	**Tue 10/1/13**	**Thu 7/3/14**
174	**C support**	**0 edays**	**100 days**	**Tue 10/1/13**	**Mon 3/3/14**
180	**DAQ Support/Cooling**	**0 edays**	**90 days**	**Fri 1/31/14**	**Thu 6/5/14**
186	**Baseplate**	**0 edays**	**90 days**	**Fri 1/31/14**	**Thu 6/5/14**
192	Integration	0 edays	10 days	Fri 6/6/14	Thu 6/19/14
193	Testing	0 edays	10 days	Fri 6/20/14	Thu 7/3/14
194	Tracker Support Complete	0 edays	0 days	Thu 7/3/14	Thu 7/3/14
195	**Services**	**0 edays**	**198 days**	**Tue 10/1/13**	**Thu 7/17/14**
196	**Motion Levers**	**0 edays**	**50 days**	**Mon 10/28/13**	**Fri 1/17/14**
202	**Vacuum Flanges/Boards/cables**	**0 edays**	**160 days**	**Tue 10/1/13**	**Mon 5/26/14**
208	**Shipping**	**0 edays**	**120 days**	**Fri 1/31/14**	**Thu 7/17/14**
214	Services complete	0 edays	0 days	Thu 7/17/14	Thu 7/17/14
215	**Integration at SLAC**	**0 edays**	**30 days**	**Mon 6/9/14**	**Fri 7/18/14**
216	Assembly	0 edays	10 days	Mon 6/9/14	Fri 6/20/14
217	Testing	0 edays	20 days	Mon 6/23/14	Fri 7/18/14
218	SVT ready to ship	0 edays	0 days	Fri 7/18/14	Fri 7/18/14
219	**Integration at JLab**	**0 edays**	**35 days**	**Mon 7/21/14**	**Fri 9/5/14**
220	Assembly	0 edays	10 days	Mon 7/21/14	Fri 8/1/14
221	Testing	0 edays	20 days	Mon 8/4/14	Fri 8/29/14
222	Installation	0 edays	5 days	Mon 9/1/14	Fri 9/5/14
223	SVT project complete	0 edays	0 days	Fri 9/5/14	Fri 9/5/14
224	**SVT DAQ**	**0 edays**	**209 days**	**Mon 8/5/13**	**Thu 6/5/14**
225	**Hybrids**	**0 edays**	**100 days**	**Mon 8/5/13**	**Fri 12/20/13**
226	Design	0 edays	40 days	Mon 8/5/13	Fri 9/27/13
227	Procurement	0 edays	10 days	Mon 9/30/13	Fri 10/11/13
228	Fabrication	0 edays	10 days	Mon 10/14/13	Fri 10/25/13
229	Assembly	0 edays	20 days	Mon 10/28/13	Fri 11/22/13
230	Testing	0 edays	20 days	Mon 11/25/13	Fri 12/20/13
231	Hybrids Complete	0 edays	0 days	Fri 12/20/13	Fri 12/20/13
232	**FE Boards**	**0 edays**	**45 days**	**Mon 12/2/13**	**Fri 2/14/14**
233	Design	0 edays	30 days	Mon 12/2/13	Fri 1/24/14
234	Procurement	0 edays	5 days	Mon 1/27/14	Fri 1/31/14
235	Assembly	0 edays	5 days	Mon 2/3/14	Fri 2/7/14
236	Firmware	0 edays	20 days	Mon 12/2/13	Fri 1/10/14
237	Testing	0 edays	5 days	Mon 2/10/14	Fri 2/14/14
238	FE Boards Complete	0 edays	0 days	Fri 2/14/14	Fri 2/14/14
239	**Flange Boards**	**0 edays**	**30 days**	**Mon 11/25/13**	**Fri 1/17/14**
240	Design	0 edays	10 days	Mon 11/25/13	Fri 12/6/13
241	Procurement	0 edays	5 days	Mon 12/9/13	Fri 12/13/13
242	Assembly	0 edays	10 days	Mon 12/16/13	Fri 1/10/14
243	Testing	0 edays	5 days	Mon 1/13/14	Fri 1/17/14
244	Flange Boards Complete	0 edays	0 days	Fri 1/17/14	Fri 1/17/14
245	**Cables**	**0 edays**	**45 days**	**Mon 2/3/14**	**Fri 4/4/14**
246	**L1-L3 Aggregators**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
251	**L1-L3 FEB Cables**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
256	**L4-L6 Aggregators**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
261	**L4-L6 FEB Cables**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
266	**FEB HV Cables**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
271	**FEB LV Cables**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
276	**FEB Data Cables**	**0 edays**	**30 days**	**Mon 2/3/14**	**Fri 3/14/14**
280	**External PS Cables**	**0 edays**	**45 days**	**Mon 2/3/14**	**Fri 4/4/14**
285	**External DAQ Cables**	**0 edays**	**35 days**	**Mon 2/3/14**	**Fri 3/21/14**
286	Design	0 edays	5 days	Mon 2/3/14	Fri 2/7/14
287	Procurement	0 edays	20 days	Mon 2/10/14	Fri 3/7/14
288	Assembly	0 edays	5 days	Mon 3/10/14	Fri 3/14/14
289	Testing	0 edays	5 days	Mon 3/17/14	Fri 3/21/14
290	Cables Complete	0 edays	0 days	Fri 4/4/14	Fri 4/4/14
291	**ATCA DAQ**	**0 edays**	**60 days**	**Wed 3/12/14**	**Tue 6/3/14**
292	**RCE Nodes**	**0 edays**	**60 days**	**Wed 3/12/14**	**Tue 6/3/14**
298	**Trigger RTM**	**0 edays**	**25 days**	**Wed 3/12/14**	**Tue 4/15/14**
303	RCE DAQ Complete	0 edays	0 days	Tue 6/3/14	Tue 6/3/14
304	**Power Supplies**	**0 edays**	**65 days**	**Fri 11/22/13**	**Thu 3/6/14**
305	Procurement	0 edays	60 days	Fri 11/22/13	Thu 2/27/14
306	Testing	0 edays	5 days	Fri 2/28/14	Thu 3/6/14
307	**Integration**	**0 edays**	**2 days**	**Wed 6/4/14**	**Thu 6/5/14**
308	Assembly	0 edays	1 day	Wed 6/4/14	Wed 6/4/14
309	Testing	0 edays	1 day	Thu 6/5/14	Thu 6/5/14
310	SVT DAQ Complete	0 edays	0 days	Thu 6/5/14	Thu 6/5/14



ID	Task Name	Leveling Delay	Duration	Start	Finish
311	**ECAL**	**0 edays**	**251 days**	**Mon 9/2/13**	**Tue 9/2/14**
312	ECAl review	0 edays	1 day	Thu 10/17/13	Thu 10/17/13
313	**Mother Boards**	**0 edays**	**121 days**	**Mon 9/2/13**	**Mon 3/3/14**
314	MB Design	0 edays	80 days	Mon 9/2/13	Tue 12/31/13
315	MB Procurement	0 edays	35 days	Mon 12/2/13	Fri 1/31/14
316	MB Tests	0 edays	30 days	Mon 1/6/14	Fri 2/14/14
317	Ship MB to Orsay	0 edays	0 days	Mon 2/17/14	Mon 2/17/14
318	Shipment	0 edays	11 days	Mon 2/17/14	Mon 3/3/14
319	**Preamplifiers**	**0 edays**	**97 days**	**Fri 11/1/13**	**Tue 4/1/14**
320	PA Parts Procurement	0 edays	36 days	Fri 11/1/13	Fri 12/20/13
321	PA Production	0 edays	42 days	Mon 1/6/14	Tue 3/4/14
322	PA Tests	0 edays	20 days	Tue 3/4/14	Mon 3/31/14
323	Last PA tested	0 edays	0 days	Tue 4/1/14	Tue 4/1/14
324	**LED Monitoring System**	**0 edays**	**175 days**	**Mon 9/2/13**	**Fri 5/16/14**
325	LMS Conceptual Design	0 edays	80 days	Mon 9/2/13	Tue 12/31/13
326	LMS Holder design	0 edays	44 days	Tue 10/1/13	Fri 11/29/13
327	LMS Holder Production	0 edays	35 days	Mon 12/2/13	Fri 1/31/14
328	LMS Mechanical Design	0 edays	40 days	Mon 1/6/14	Fri 2/28/14
329	LMS Connection Board Design	0 edays	40 days	Mon 1/6/14	Fri 2/28/14
330	LMS Connection Board Prod	0 edays	41 days	Mon 2/3/14	Mon 3/31/14
331	Procurement LED	0 edays	20 days	Mon 1/6/14	Fri 1/31/14
332	LED Tests	0 edays	41 days	Mon 2/3/14	Mon 3/31/14
333	Ship to France	0 edays	0 days	Tue 4/1/14	Tue 4/1/14
334	Shipment	0 edays	11 days	Tue 4/1/14	Tue 4/15/14
335	LED Welding	0 edays	23 days	Wed 4/16/14	Fri 5/16/14
336	**New APDs**	**0 edays**	**169 days**	**Tue 10/1/13**	**Mon 6/9/14**
337	Tooling for Assembly	0 edays	169 days	Tue 10/1/13	Fri 6/6/14
338	Tooling for Tests	0 edays	41 days	Fri 12/20/13	Fri 2/28/14
339	Ship tools for APDs	0 edays	0 days	Fri 2/28/14	Fri 2/28/14
340	Shipment	0 edays	11 days	Mon 3/3/14	Mon 3/17/14
341	Procurement APDs	0 edays	76 days	Mon 12/2/13	Mon 3/31/14
342	APDs Delivered at Orsay	0 edays	0 days	Mon 3/31/14	Mon 3/31/14
343	APDs delivered at INFN	0 edays	0 days	Mon 3/31/14	Mon 3/31/14
344	**APD Crystal gluing**	**0 edays**	**59 days**	**Tue 3/18/14**	**Fri 6/6/14**
348	Last Crystal Characterized	0 edays	0 days	Mon 6/9/14	Mon 6/9/14
349	**Mechanics**	**0 edays**	**152 days**	**Fri 11/1/13**	**Mon 6/16/14**
350	Dismounting ECal	0 edays	21 days	Fri 11/1/13	Fri 11/29/13
351	Ship ECal Boxes to IPN	0 edays	0 days	Mon 1/6/14	Mon 1/6/14
352	Shipment ECal	0 edays	13 days	Mon 1/6/14	Wed 1/22/14
353	Work on Thermal Box	0 edays	63 days	Thu 1/23/14	Mon 4/21/14
354	Structure Modifications	0 edays	20 days	Mon 2/3/14	Fri 2/28/14
355	Mounting System Design	0 edays	20 days	Mon 2/3/14	Fri 2/28/14
356	MS Construction	0 edays	21 days	Mon 3/3/14	Mon 3/31/14
357	PA Rails Install	0 edays	43 days	Tue 3/4/14	Thu 5/1/14
358	LMS Boards Install	0 edays	11 days	Fri 5/2/14	Fri 5/16/14
359	Ship to JLab	0 edays	0 days	Mon 5/19/14	Mon 5/19/14
360	Shipment	0 edays	21 days	Mon 5/19/14	Mon 6/16/14
361	**Assembly**	**0 edays**	**55 days**	**Tue 6/17/14**	**Tue 9/2/14**
362	Assemble ECal	0 edays	22 days	Tue 6/17/14	Wed 7/16/14
363	ECal Assembled	0 edays	0 days	Thu 7/17/14	Thu 7/17/14
364	ECal Commissioning	0 edays	33 days	Thu 7/17/14	Mon 9/1/14
365	ECal Ready for data taking	0 edays	0 days	Tue 9/2/14	Tue 9/2/14
366	**TDAQ**	**0 edays**	**336 days**	**Fri 3/1/13**	**Fri 6/27/14**
367	TDAQ Review	0 edays	1 day	Wed 11/20/13	Wed 11/20/13
368	EPICS information into data stream	0 edays	4 wks	Mon 1/6/14	Fri 1/31/14
369	Software TDAQ	0 edays	4 wks	Mon 1/6/14	Fri 1/31/14
370	Hardware TDAQ	0 edays	4 wks	Fri 3/1/13	Thu 3/28/13
371	Update firmware on FADC250	0 edays	4 wks	Mon 9/2/13	Fri 9/27/13
372	New firmware for cluster finding	0 edays	4 wks	Mon 9/30/13	Fri 10/25/13
373	New firmware for SSP	0 edays	2 wks	Mon 10/28/13	Fri 11/8/13
374	Trigger monitoring tools	0 edays	4 wks	Mon 11/11/13	Fri 12/6/13
375	TDAQ ready	0 edays	0 days	Fri 12/6/13	Fri 12/6/13
376	Data Storage	0 edays	105 days	Mon 2/3/14	Fri 6/27/14
377	**Slow Control**	**0 edays**	**187 days**	**Tue 11/19/13**	**Wed 8/20/14**
378	Specs avaialable - Slow Control review	0 edays	0 days	Thu 12/5/13	Thu 12/5/13
379	Chiller control programming	0 edays	2 wks	Thu 2/13/14	Wed 2/26/14
380	I/O modules for control	0 edays	7 mons	Thu 12/5/13	Wed 7/2/14
381	Sensor readout programming	0 edays	30 wks	Tue 11/19/13	Tue 7/1/14
382	SVT voltage control	0 edays	3 wks	Mon 3/24/14	Fri 4/11/14
383	ECAL voltage control	0 edays	13 wks	Thu 12/5/13	Wed 3/19/14
384	SVT motor controls	0 edays	2 wks	Mon 7/21/14	Fri 8/1/14
385	Target motor control	0 edays	1 wk	Mon 7/28/14	Fri 8/1/14
386	Software interlock	0 edays	17 wks	Tue 1/28/14	Mon 5/26/14
387	Hardware interlocks	0 edays	7 mons	Mon 1/6/14	Fri 7/18/14
388	Beamline control screens	0 edays	5 mons	Mon 2/10/14	Fri 6/27/14
389	EPICS Scalers programing	0 edays	34 wks	Thu 12/5/13	Wed 8/13/14
390	Alarms configuration	0 edays	1 wk	Thu 8/14/14	Wed 8/20/14
391	Archiving of controls	0 edays	17 wks	Thu 4/24/14	Wed 8/20/14
392	Slow Control Ready	0 edays	0 days	Wed 8/20/14	Wed 8/20/14
393	**Installation & Commissioning**	**0 edays**	**585 days?**	**Fri 3/1/13**	**Thu 6/25/15**
394	SVT installation	0 edays	2 days	Fri 3/1/13	Mon 3/4/13
395	SVT Commissioning	0 edays	40 hrs	Thu 8/28/14	Wed 9/3/14
396	ECAL Commissioning	0 edays	40 hrs	Thu 9/4/14	Wed 9/10/14
397	TDAQ Commissioning	0 edays	2 wks	Fri 3/1/13	Thu 3/14/13
398	Slow Control Commissioning	0 edays	1 wk	Thu 8/21/14	Wed 8/27/14
399	HPS ready for the beam	0 edays	0 days	Fri 9/26/14	Fri 9/26/14
400	**Off-Project Milestones**	**0 edays**	**433 days?**	**Tue 10/1/13**	**Thu 6/25/15**
401	**Beamline**	**0 edays**	**52 days?**	**Thu 8/28/14**	**Mon 11/10/14**
402	Hall-B transport line	0 edays	1 day?	Thu 8/28/14	Fri 8/29/14
403	Hall-B upstream beamline ready	0 edays	0 days	Fri 8/29/14	Fri 8/29/14
404	Commissioning of RF separator	0 edays	1 day?	Fri 10/31/14	Mon 11/3/14
405	1/2/3 pass separaton and beam delivery	0 edays	1 day?	Fri 11/7/14	Mon 11/10/14
406	**Hall-B Work**	**0 edays**	**103 days**	**Tue 10/1/13**	**Thu 3/6/14**
407	CLAS12 PCAL and FTOF are mounted	0 edays	98 days	Tue 10/1/13	Thu 2/27/14
408	Preparing alcove	0 edays	103 days	Tue 10/1/13	Thu 3/6/14
409	Forward carriage move upstream	0 edays	4 days	Mon 3/3/14	Thu 3/6/14
410	**CLAS12 Torus assembly**	**0 edays**	**264 days**	**Mon 6/9/14**	**Thu 6/25/15**
411	Start assembly of the Spit	0 edays	8 days	Mon 6/9/14	Wed 6/18/14
412	Install Torus Coil	0 edays	112 days	Mon 7/21/14	Tue 1/6/15
413	Cold-to-worm support	0 edays	10 days	Mon 3/16/15	Fri 3/27/15
414	Weld V	0 edays	30 days	Mon 3/2/15	Fri 4/10/15
415	Orient and secure Torus to Hall B floo	0 edays	11 days	Mon 4/13/15	Mon 4/27/15
416	Connect leads and piping	0 edays	15 days	Tue 4/28/15	Mon 5/18/15
417	Leak test and Pump V	0 edays	18 days	Tue 6/2/15	Thu 6/25/15



Appendix B Non-Costed Scientific Manpower

		PM	Beamline	SVT	SVT DAQ	ECAL	TDAQ	Slow Control	Software	I&C	FTE
M. Battaglieri	INFN					0.21				0.02	0.23
A. Celentano	INFN					0.21			0.12		0.33
Stuart Fegan	INFN								0.3		0.30
A.D'Angelo	INFN					0.21					0.21
A.Rizzo	INFN					0.21			0.12		0.33
L.Colaneri	INFN					0.21			0.52		0.73
G.Simi	INFN								0.3		0.30
N.Randazzo	INFN					0.2					0.20
M.DeNapoli	INFN					0.2					0.20
R.Devita	INFN					0.1			0.12		0.22
M.Carpinelli	INFN					0.4			0.1		0.50
V.Sipala	INFN					0.3					0.30
M.Osipenko	INFN								0.2		0.20
S.Aiello	INFN					0.2					0.20
E.Leonora	INFN					0.2					0.20
D.Calvo	INFN					0.2					0.20
A.Filippi	INFN								0.3		0.30
C.Ventura	INFN					0.2					0.20
Raphael Dupre	IPNO					0.63			0.08	0.02	0.74
Gabriel Charles	IPNO					0.50			0.50		1.00
Stepan Stepanian	JLAB	0.05	0.10			0.10				0.10	0.35
Arne Freyberg	JLAB		0.05								0.05
Hovanes Hegiyan	JLAB							0.21		0.02	0.23
Serguei Boyarinov	JLAB						0.25				0.25
Maurizio Ungaro	JLAB								0.10		0.10
FX Girod	JLAB		0.40								0.40
Yuri Gernstein	Rutgers								0.21		0.21
Tim Nelson	SLAC			0.70	0.25					0.05	1.00
Per Hansson	SLAC			0.35	0.40				0.20	0.05	1.00
Sho Uemura	SLAC			0.20	0.20				0.20	0.02	0.62
Matt Graham	SLAC								0.50		0.50
Jeremy McCormick	SLAC								0.20		0.20
Norman Graf	SLAC								0.50		0.50
John Jaros	SLAC	1									1.00
Homer Neal	SLAC								0.08		0.08
Takashi Maruyama	SLAC		0.40	0.35					0.20	0.05	1.00
Ken Moffeit	SLAC		1.00								1.00
Clive Field	SLAC		0.17								0.17
Vitaliy Fadeyev	UCSC			0.12	0.04						0.15
Forest McKinney	UCSC			0.18							0.18
Omar Moreno	UCSC			0.13	0.15				0.21	0.02	0.51
Kyle McCarthy	UNH					0.25			0.25		0.50
Maurik Holtrop	UNH								0.21	0.02	0.23
Annie Simonyan	Yerevan							0.50			0.50
Nerses Gevorgyan	Yerevan							0.50			0.50
Holly Szumila-Vance	W&M		0.25			0.50			0.25		1.00
Total FTE by Subsytem			**2.37**	**2.02**	**1.04**	**5.04**	**0.25**	**1.21**	**5.78**	**0.37**	**19.13**

Appendix C: Costed Engineering and Technical Manpower

Mechanical Engineering		**PM**	**Beamline**	**SVT**	**SVT DAQ**	**ECAL**	**TDAQ**	**Slow Control**	**Software**	**I&C**	**Total**
Marco Oriunno	SLAC	0.30	0.10	0.20						0.12	0.72
Shawn Osier	SLAC			0.42							0.42
Matt Swift	SLAC		0.04	0.29							0.33
Matt McCulloch	SLAC		0.02	0.40							0.42
MD	JLAB		0.46								0.46
ME	JLAB		0.09								0.09
ME Accelerator JLAB	JLAB		0.02								0.02
MT Accelerator JLAB	JLAB		0.04								0.04
P. Rosier	IPNO					0.04				0.02	0.06
E. Rindel	IPNO					0.17				0.02	0.19
F. Pratolongo	INFN					0.13					0.13
G. Mini	INFN					0.13					0.13
MT Hall-B	JLAB					0.06					0.06
Electrical Engineering											
Ryan Herbst	SLAC				0.36					0.13	0.49
Ben Reese	SLAC				0.35						0.35
Tung Phang	SLAC			0.02							0.02
Ben Raydo (EE)	JLAB						0.50				0.50
EE Hall-B JLAB	JLAB									0.04	0.04
ET Hall-B JLAB	JLAB									0.04	0.04
ET Hall-B JLAB	JLAB									0.02	0.02
EE Hall-B JLAB	JLAB									0.02	0.02
EE Accelerator JLAB	JLAB							0.23			0.23
Emmanuel Rauly	IPNO									0.02	0.02
						0.13					0.13
Total FTE by Subsytem		**0.30**	**0.76**	**1.33**	**0.71**	**0.52**	**0.50**	**0.23**		**0.42**	4.78