Department of Energy
Washington, DC 20585

MAY 12 2011

Dr. John Jaros
SLAC National Accelerator Laboratory
2575 Sand Hill Road, MS 43
Menlo Park, CA 94025

Dear Dr. Jaros:

I have enclosed the report of the Department of Energy (DOE), Office of High Energy Physics review of the Heavy Photon Search (HPS) Test Run experiment held on March 1, 2010, at the DOE Germantown facility. The goal of the review was an assessment of the plans of the HPS Test Run in the Spring of 2012 to meet the requirements of the Program Advisory Committee of the Thomas Jefferson National Accelerator Facility.

I would like to thank you and your staffs for the clarity of the presentations and the general quality of the review. The review proceeded smoothly and the presentations by the HPS team were technically sound, well organized, and informative.

The review committee was favorably impressed by the review and its associated materials. They did, however, make several comments and recommendations which the HPS team should consider. Please address the review committee's suggestions and recommendations in a response to this office within the next three weeks.

We hope that the review report is helpful to you in planning the HPS Test Run. We look forward to a successful and informative test run which should lead to a later review of the full HPS experimental run in the upgraded 12 GeV beam at The Thomas Jefferson National Accelerator Facility in 2014-2015.

Sincerely,

Michael Procario
Acting Associate Director of Science
for High Energy Physics

Enclosure

cc: D. MacFarlane, SLAC

Office of High Energy Physics
Report on the

The Heavy Photon Search Experiment at TJNAF

The Test Run

March 1, 2011

Executive Summary

The Review of the Heavy Photon Search (HPS) experiment's Test Run at the Thomas Jefferson National Accelerator Facility (TJNAF or "JLAB") was held on March 1, 2010 at the Department of Energy's Germantown facility. The HPS experiment is a "beam dump" experiment that will search for a hypothetical particle, the "heavy" or "dark" photon, which is the quantum of the force that acts in a new hypothetical dark sector of matter. The purpose of the review was to assess the HPS group's plans for a test run to validate their detector designs in the 6 GeV beam of the Continuous Electron Beam Accelerator Facility (CEBAF) during the summer of 2012. The Program Advisory Committee (PAC) of JLAB ruled at their January 14, 2011 meeting that a successful test run of the HPS detector is a prerequisite to the full scale running in the upgraded 12 GeV beam in FY2014-15.

Four expert reviewers from the high energy physics community heard HPS presentations on scientific background and detector design developments. In particular, the HPS team was instructed to address four charge elements:

1. The potential scientific significance and the reach of the Stage I Test Run and, separately, the significance and reach of the full HPS experimental program planned for the upgraded 12 GeV accelerator facility. Comparisons of physics reach with competing experiments in the field should be made explicit.
2. The technical readiness of the Stage I Test Run of the HPS. Potentially high risk elements of the experiment include the target design, the silicon microstrip tracker/vertex, the Electromagnetic Calorimeter (ECAL), the muon detector and the high rate Data Acquisition (DAQ). The review committee will evaluate the status of the designs and the technical risks associated with these elements.
3. The cost and schedule of the Stage I Test Run. The components of the Test Run and its preparations should be organized in the form of a project with personnel and budget tables for each major activity.
4. The cost and schedule contingencies attached to each activity. Critical manpower and activities should be identified. The experiment's dependency on TJNAF plans for experimental Hall B or other external factors should be addressed.

The reviewers were impressed with the HPS experiment and felt that the test run is feasible but challenging. However, they remarked that the contingencies for the test run were generally small and the schedule was very challenging. They recommended that a single leader for the test run be named to monitor the major risks and that a project engineer should manage the cost and schedule. Follow-up discussions with JLAB management indicated that the HPS test run does not have the highest priority for the use of Hall B in 2011-2012. Therefore, HPS was asked to put together a plan for their test run activities at other facilities and argue that success at these alternative sites would accomplish the goals of the original test run. A document entitled "HPS Test Run Contingency Plan" was received on March 19, 2011 and it made the case that parasitic runs at JLAB and runs in the new SLAC test beam will meet the requirements of the JLAB PAC.

Introduction and Background

The Heavy Photon Search (HPS) Test Run that was subject to this review is the first stage of the full HPS experiment which will search for a new heavy vector boson, "heavy photon", at Jefferson Laboratory. The heavy photon is a hypothetical particle that would be the transmitter of force in a new dark sector that would, in principle, address the dark matter problem of the universe. Such models are gaining interest in the theory community and are now considered able competitors to WIMPs (weakly interacting massive particle) which are suggested by supersymmetric extensions of the Standard Model.

The HPS Test Run was reviewed and approved by the Jefferson Laboratory Program Advisory Committee (PAC) on January 14, 2011. In the approval letter the PAC recommended that the test run occur at the 6 GeV facility before its shutdown in the Fall of 2012 for an upgrade to 12 GeV. The full HPS experiment will run after the upgrade in 2014 or 2015, if the test run is successful and addressees the requirements of the JLAB PAC.

The HPS experiment proper will utilize a compact, large acceptance forward spectrometer, silicon microstrip vertex tracker, and PbWO4 electromagnetic calorimeter to search for electro-produced heavy photons decaying to e+e- in the mass range of 20 to 1000 MeV/c^2. Heavy photons would be visible as narrow resonances above the copious QED trident background, and by detection of their secondary decay vertices downstream of the target. High luminosities are required to search for heavy photons because of their weak couplings to electrons and the prolific backgrounds. HPS achieves great sensitivity by exploiting the Continuous Electron Beam Accelerator Facility's (CEBAF's) 100% duty cycle, high luminosities, and 40 MHz continuous readout, and by placing silicon microstrip detectors and the electromagnetic calorimeter used for triggering in close proximity to a hot electron beam.

The goal of the HPS Test Run is to verify detailed full Monte Carlo simulations that show that microstrip occupancies and ECAL trigger rates are manageable in this environment with a simplified version of the HPS apparatus. The Test Run should also demonstrate that the tracker and ECAL sensors and readout are operable, and that the data acquisition can run at very high rates. The Test Run apparatus is capable of high rate triggering, full track finding, momentum measurement, and vertexing, so it is capable of demonstrating the physics capability of the full HPS. In particular, the Test Run apparatus is capable of extending the search for heavy photons into new regions of the heavy photon parameter space (coupling and mass) with relatively short runs of one or two weeks. The HPS Test Run experiment is planning to proceed to engineering design, fabrication, assembly and test over the remainder of 2011, and to be ready for full integration and installation by March, 2012. A one month test run, including time for installation, commissioning, and a week of data taking, will fulfill the HPS Test Run goals.

The HPS team presented cost estimates for engineering, designing, fabricating, assembling, testing, and installing the Heavy Photon Search Test Run in their proposal and review presentations. Their request to the Office of High Energy Physics of the Department of Energy for the test run is $751,000. This total does not reflect contributions in kind from SLAC, FNAL JLAB and Orsay. The test run is planning on the donation of the silicon microstrip sensors from

Fermilab, the use of some DAQ crates and equipment from SLAC, and several contributions from JLAB, including PbWO4 calorimeter crystals, the chicane and analyzing magnets, magnet power supplies, and beam diagnostic apparatus. Much of the calorimeter readout electronics utilizes designs which are already in place for the Hall B 12 GeV upgrade, will be used without cost. Additional cost savings should come from utilizing the Flash Analog-to-Digital modules (FADCs) and data acquisition system being developed for the upgraded CLAS12 detector. The Orsay group is donating engineering and design efforts for the ECAL and its vacuum chambers.

The costs were provided in a WBS summary table which can be found in the proposal. Contingencies have been set at 30% for labor and 35% for M&S at SLAC, and somewhat lower at JLAB. The contingency for commercial items is generally about 10%. The experiment's DAQ and beamline cost estimates have been made by engineering groups at SLAC and JLAB. The Silicon Vertex Tracker (SVT) estimates came from physicists and engineers on the project, with experience in designing and fabricating silicon detector systems. The ECAL estimates come from physicists and engineers at JLAB who have constructed a similar system, the CLAS IC, in the recent past.

A high level cost breakout for the test run is included here.

Item	**Cost ($K)**
Beamline	138
Si Tracker	168
ECAL	175
SVT DAQ	200
ECAL Trigger/DAQ	32
Travel	38
TOTAL	**751**

The HPS Test Run schedule goal is to be ready for installation by March, 2012, and proceed with commissioning, and data taking during late Spring 2012, before the down for the 12 GeV Upgrade. Schedules for each of the major subsystems of the experiment were presented in the proposal and at the review. The schedule contingency is 10%.

The HPS team presented WBS tables detailing the manpower needs of the various activities needed to be completed before the test run, including design, fabricate, assemble, test, install, and commission. The HPS Collaboration, which consists of 60 individuals, has assigned particular physicists and engineers within their ranks for each of these. The HPS collaboration is managed by its three spokespersons, Maurik Holtrop, John Jaros, and Stepan Stepanyan.

The reviewers' analyses of the four charge elements of the review follow.

1. **The potential scientific significance and the reach of the Stage I Test Run and, separately, the significance and reach of the full HPS experimental program planned for the upgraded 12 GeV accelerator facility. Comparisons of physics reach with competing experiments in the field should be made explicit.**

Findings

Recent astrophysical results and speculations about dark matter have motivated a search for heavy photons in the few MeV to 1 GeV mass region with couplings to the photon of between 10^{-2} and 10^{-5} of that of the electron charge.

The HPS experiment can explore a section of the parameter space of light, weakly-coupled vector particles that are possible products of dark matter interactions or decays that is unique among the JLAB proposals.

The HPS experiment is primarily a displaced vertex search for light vector particles that decay to lepton pairs. There is also a "bump-hunt" component in which the vertices are not required to be displaced.

One of the stated goals of the HPS test run is to be sensitive to a good deal of the g-2 parameter space (that range of heavy photon masses and couplings which could explain the possible g-2 anomaly), although the highest priority is to test critical aspects of the experimental design.

Between them, the two other proposed heavy photon searches at JLAB aim to cover the entire g-2 region (the A' Experiment (APEX) covers down to ~90 MeV, DarkLight up to ~100 MeV). APEX is approved for running but may not get beam time before the May 2012 shutdown. It can run at a month's notice and cover its portion of the parameter space quickly. DarkLight can't run until 2015, but it also claims it can get its results within one month of starting data collection. HPS requests one month for a test run of which one week will be actual data taking. By contrast, the full HPS requires two 3-month runs. Depending on the sequencing of the experiments, the g-2 region may be covered before HPS can deliver a result in this region.

For a given beam energy the mass reach of the experiment is limited by how close to the beam plane the apparatus can be placed. The proponents are interested in extending the search to lower mass and believe that it might be possible to use a lower beam energy (~1 GeV). This would be more difficult after the CEBAF upgrade since to get to 1GeV would require the top energy to be 6 GeV.

Comments

The parameter space displayed by the HPS collaboration was said to be the "region of interest", but it was admitted by the proponents that a null result over the entire region would not kill any of the popular theories.

There is considerable competition among the various heavy photon search experiments, both in the US and abroad. Within Germany, the Mainz experiment claims it can also eventually do a displaced vertex search and cover much of the HPS region (see crunch.ikp.physik.tu.darmstadt.de/erice/2010/sec/talks/sunday/Merkel.pdf)

The scientific merit of the HPS Test Run is high, as is the merit of the full HPS experiment. It allows detection of a heavy photon with masses between 20 and 60 MeV, a region not covered by APEX, and, in addition, probes lower coupling limits with the displaced vertices. Overall, the HPS experiment is superior in the high coupling region when compared to the other experiments being planned, or possible from existing data analysis, and it also has the potential to probe an entirely new region of phase space. It appears that there may be little need for running APEX if HPS were shown in the Test Run to be capable of probing the low mass region.

If the full HPS experiment can really be done for ~$3M, and if there is not a prospect of an experiment with similar sensitivity elsewhere, it seems quite a worthwhile project.

HPS should try to run at 1 GeV and cover as wide a region of parameter space as possible. The potential reach of the HPS experiment is one of its foremost strengths.

Recommendations

None.

2. The technical readiness of the Stage I Test Run of the HPS. Potentially high risk elements of the experiment include the target design, the silicon microstrip tracker/vertex, the ECAL, the muon detector and the high rate DAQ. The review committee will evaluate the status of the designs and the technical risks associated with these elements.

Findings

The HPS Test Run is required by the JLAB PAC because there are several high risk technical challenges in the operation of the full HPS detector. The specific technical challenges which must be demonstrated in the Test Run are:

> The proximity of the silicon sensors to the high intensity electron beam will cause high rates of noise hits and result in degraded pattern recognition and track reconstruction.
>
> The proximity of the calorimeter crystals to the beam, the resulting radiation damage and high hit rate in the innermost crystals due to electron and photons which have scattered out of the beam.
>
> The calorimeter trigger, and in particular the Crate Trigger Processor (CTP), which must reduce the trigger rate from background processes to < 25kHz.
>
> The engineering of the target, which must be thin to insure high signal acceptance, low rates from unwanted processes and a very high intensity beam which will cause target heating.

Comments

The HPS team is making good technical progress on the four main technical challenges cited above. The most demanding task is the electronics to sample the colorimeter signals in the 4x4ns buckets and to form a trigger decision every 8ns. A key component in this is the 250 MHz FADC being developed for the CLAS12. It has low to moderate risk. The trigger decision is made in a Field Programmable Gate Array (FPGA) in the CTP and is a conventional but somewhat demanding programming task. There are no "showstoppers" here. If successful, the results of the Test Run will demonstrate the feasibility of the full HPS experiment, and determine the mass and coupling limits testable in the full run for a given beam exposure.

It would be desirable to raster the beam on the target during the test run. This would determine whether such a technique would be possible for the full experiment. The bend-plane resolution in the silicon is expected to be ~60μ during the test run so that the resolution that the rastering gives on target should be measurable to this level. Rastering may only be possible if the test run slips beyond the 6GeV shutdown, however, due to space limitations in Hall B.

Other than beam availability, the proposed beam delivery and beam parameters needed for the test run seem to be already demonstrated. The target design seems to be within the boundaries of previous experience at JLAB. These do not appear to be risk items for the test run.

The technical risks for the construction of a silicon tracker as proposed are low. This is because all the long lead-time items (integrated circuits and sensors) already exist and are very mature and involve very well understood technology. The proposed assembly of these components is by no means aggressive. Assembly of such silicon devices requires the usual attention to detail, but there is plenty of expertise among the proponents, and the facilities exist and are available to carry out the work expeditiously.

The main technical uncertainty is whether the silicon tracker will perform as simulated, without unexpected degradation from operation very close to the dead zone. The proponents have convincingly argued that the Test run cannot fail in this respect. Either the performance will be as expected and the Test run will yield new physics results, or the performance will be significantly different from present simulations, in which case the Test run may not yield significant physics, but it will have removed this critical uncertainty from the HPS main run. The main risk to such a dual purpose test is the possibility of inconclusive results that could leave the technical questions not fully answered. To minimize this risk one could perhaps build the Test run silicon tracker not in a completely uniform way, as would be desired for a final instrument, but with some variants (for example different sensors on one of the planes). Different sensors may not hurt the physics potential, yet may prove invaluable should a serious problem arise with operating the CDF run2b sensors close to the beam.

It was not clear that the same silicon design would be reused in the 12 GeV full HPS run. Therefore it may be useful to learn how other sensor designs that already exist behave in the real conditions. Perhaps as a stretch goal (prepare for the worst but plan for the best) could be to have a sixth tracker plane that is left un-instrumented in the baseline, but with the mechanics and services ready to be connected to it if things go well.

For the electromagnetic calorimeter, availability of the lead tungstate crystals seems clear. A point raised during the review was whether light monitoring with calibration flashes is required. (The point here is that radiation levels in the crystal calorimeter could in principle affect the crystal's light output which in turn could affect the electron trigger. Remedies using the existing light monitoring system will require changes to the design of the ECAL enclosure.) The fibers needed for this are already in place on the crystals, but were not used in the design proposed. The thermal enclosure for the scintillator blocks is a significant cost. This enclosure which will be designed by French collaborators, but then built under this proposal. Concerns were raised during the review that such an arrangement could lead to a significant cost increase. It also presents a technical and schedule risk.

A review of the enclosure design and fabrication schedule as early as possible would be useful. The design of the vacuum chamber for the calorimeter midplane seems to be under control. The weak points have been identified and the modeling seems adequate to validate a final design.

The data acquisition system presents a significant technical risk to obtaining physics results, because some elements still need to be developed, including hardware, software, and firmware. However, note that engineering results needed to assess background rates and operation close to the dead zone can be obtained with very rudimentary data acquisition: it is only the physics goals of the Test run that see a risk from DAQ.

Recommendations

None

3. The cost and schedule of the Stage I Test Run. The components of the Test Run and its preparations should be organized in the form of a project with personnel and budget tables for each major activity

Findings

The schedule for getting the test run in before the 6 GeV shutdown is very tight.

The schedule presented in the Test Run proposal does not show float in many of the sub-elements. It also does not include any milestones. The availability of key components, such as FADC's, does not appear on the schedule. The overall schedule float is at best 6 weeks.

Although the schedule is tight, it can be achieved if HPS management applies close control to task accomplishment and decision making.

The project doesn't have a formal manager and coordination seems to be in the hands of John Jaros.

The cost estimate in the proposal prepared for the Test Run reflects an improved understanding of expected costs from those presented in the earlier full proposal delivered to the JLAB PAC in January, such as for beam-line components and engineering. The cost basis is largely from past engineering experience of similar and ongoing projects and vendor quotes,

Comments

The integration task may be more difficult than the HPS team has planned for. The team should consider whether they need more help in this area.

The scheduling of beam time for the Test run remains as the largest single risk to the program.

The DAQ development is included in the proposed budget, but not in great detail. An obvious risk is that integration of all elements may take longer than expected. Earlier "system integration" tests as components become available would be useful.

Appointment of a project engineer in charge of system integration may be needed. However, SLAC staff has demonstrated considerable skill in this area, for example, in their deployment of RCE data acquisition boards provided for ATLAS R&D activities.

Recommendations

A single leader should be named to oversee the test run and to coordinate and integrate all the activities into a coherent whole. The leader should plan test run activities well in advance and monitor the major risks, including system integration and scheduling. The leader should report to the Office of High Energy Physics on a regular basis.

4. The cost and schedule contingencies attached to each activity. Critical manpower and activities should be identified. The experiment's dependency on TJNAF plans for experimental Hall B or other external factors should be addressed.

Findings

CEBAF shutdown for the 12 GeV upgrade is scheduled for 12 May 2012. This is a firm date in lab planning.

None of the heavy photon searches has a guaranteed run between now and when CEBAF is shut down for the 12 GeV upgrade. The HPS test run (in Hall B) is thought to have a better chance than APEX (in Hall A) because the competing Hall B experiment is having difficulty getting its apparatus ready.

Comments

The schedule contains a minimal level of float. There is insufficient detail in the schedule to determine the critical path and therefore it is not possible to determine if increased funding through use of contingency could improve the level of schedule float.

The cost contingency has been evaluated aggressively. The contingency on materials is 25% and on labor it is 28%, which are at the low ends of standard practice.

The budget presented is reasonable overall, but depends on many in-kind contributions.

The "in-kind" contributions of technical labor include a total of 480 hours of engineers, 180 hours of designers, and 80 hours of technicians to be provided by SLAC. There are 200 hours of engineers to be provided by Orsay. These free contributions have no assigned contingency. It is not clear what happens if one of these has been underestimated: will SLAC and Orsay provide extra labor as needed, effectively promising a deliverable rather than people's time, or must the project pay for extra time that may be needed to complete a job?

It is a serious concern that JLAB has not approved beam time for the Test Run before the May 2012 shutdown. This is a potential showstopper. Another concern is the significant overlap of scientific personnel between HPS and APEX. Is it realistic for these individuals to work concurrently on both projects?

Recommendations

Appoint a project engineer to oversee the Test Run with control of the contingency funds. This engineer would work closely with the overall leader of the test run, a position which was recommended in the review of Charge Element 3 above.

Identify float in the appropriate sub-elements of the schedule.

Include the availability of contributed components to the schedule, such as FADCs, power supplies and mechanical structures.

Add milestones to the schedule, such as "component X ready for system integration", "construction design review", etc.

APPENDIX A

Charge Letter to HPS Team

Prof. J. Jaros
SLAC National Accelerator Laboratory
2575 Sand Hill Road, Mail Stop 43
Menlo Park, CA 94025

Dear Prof. Jaros:

The field of experimental searches for dark matter in the universe is particularly active at this time and a direct discovery of dark matter is anticipated in the not-too-distant future. Such a discovery of physics beyond the Standard Model would be of profound importance. One of the possible candidate theories describing dark matter contains a "heavy photon" which couples weakly to conventional flavor physics. Theoretical studies indicate that such heavy photon theories are capable of explaining some hints of physics beyond the Standard Model suggested by current experiments.

As spokesperson for the proposed Heavy Photon Search (HPS) experiment at the Thomas Jefferson National Accelerator Facility (TJNAF), I am writing to inform you that the Office of High Energy Physics (HEP) plans to conduct a peer review of the HPS proposal. The review will occur at the Germantown facility of the Department of Energy on Tuesday, March 1, 2011. A review panel of experts in high energy experimental physics is being convened for this task.

The review will consider both the near term Stage I Test Run, which was approved on January 14, 2011 by the TJNAF Program Advisory Committee, as well as the longer term plans for the HPS to use the upgraded 12 GeV facility currently under construction. Each panel member will evaluate background material on the experiments and will evaluate all the presentations at the March 1 review. The focus of the review will be on understanding:

- The potential scientific significance and the reach of the Stage I Test Run and, separately, the significance and reach of the full HPS experimental program planned for the upgraded 12 GeV accelerator facility. Comparisons of physics reach with competing experiments in the field should be made explicit.

- The technical readiness of the Stage I Test Run of the HPS. Potentially high risk elements of the experiment include the target design, the silicon microstrip tracker/vertex, the ECAL, the muon detector and the high rate DAQ. The review committee will evaluate the status of the designs and the technical risks associated with these elements.

- The cost and schedule of the Stage I Test Run. The components of the Test Run and its preparations should be organized in the form of a project with personnel and budget tables for each major activity.

- The cost and schedule contingencies attached to each activity. Critical manpower and activities should be identified. The experiment's dependency on TJNAF plans for experimental Hall B or other external factors should be addressed.

Each committee member will be asked to review these aspects of the HPS project and write an individual report on his/her findings. The final reports will be due at the Department of Energy two weeks after completion of the review. John Kogut, the Federal Project Manager for electron accelerator based research, will collect the reports and compose a final summary report based on the information in the letters and the discussions at the panel review.

The review will consist of a morning of presentations and an afternoon of Q&A and executive sessions. The later part of the afternoon will include a session of preliminary report writing and a brief close-out. Preliminary findings, comments, and recommendations will be presented to you at the close-out. You should work with John Kogut to make an agenda which can accommodate these goals.

We greatly appreciate your willingness to assist us in this review. A successful review is a crucial step in implementing your proposed plans.

We look forward to a very informative and stimulating review.

Sincerely,

Mike Procario

Acting Associate Director

Office of High Energy Physics

APPENDIX B

Reviewers for HPS Teest Run Review, March 1, 2011, GTN

Laurie Littenberg (BNL) littenbe@bnl.gov

Maurice Garcia-Sciveres (LBNL) mgs@lbl.gov

Roger Rusack (Minn) rusack@hep.umn.edu

James Proudfoot (ANL) proudfoot@anl.gov

List of DOE participants

G. Crawford (HEP)

J. Kogut (HEP)

APPENDIX C

Agenda for HPS Review March 1 2011 Germantown DOE Building Z-231

8:30	Executive Session	
9:00	Introduction and Overview (15+5)	John Jaros/Takashi Maruyama
9:30	Motive, Scientific Significance, and Reach (20+10)	Mathew Graham
10:00	Beamline, Beam Requirements, Procedures (20+10)	Stepan Stepanyan
10:30	Coffee Break	
11:00	Si Tracker/Vertexer and Performance (20+10)	Tim Nelson
11:30	Ecal/Trigger/DAQ (20+10)	Maurik Holtrop
12:00	Project Cost and Schedule and Conclusions (20+10)	John Jaros
12:30	Working Lunch	
1:30	Q&A	
2:00	Executive Session	
3:00	Closeout	