Update on the Heavy Photon Search Experiment

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The Heavy Photon Search (HPS) experiment at Jefferson Lab, E12-11-006, is searching for new heavy vector-boson(s) aka 'heavy' or 'dark' photon(s), called A′ in the proposal, in the mass range of 20 MeV/c^2 to 500 MeV/c^2 and couplings $\epsilon > 10^{-10}$. The experiment was first proposed to PAC37 in 2011, then to PAC 39 in 2012 after a short test run and was approved for 180 days of running with an "A" rating. Since then HPS was able to build the detector, complete successfully two engineering runs in 2015 and 2016 with 1.1 GeV and 2.2 GeV beams, respectively, and run its first physics run in summer of 2019 using 4.56 GeV electron beam. The engineering runs, with merely 2 PAC days of production data at each energy, resulted in the first HPS physics publications as well as two technical papers, and six Ph.D. theses. The engineering runs also lead to the important upgrades of the HPS detector and the trigger system that enhanced its performance significantly especially for A′ displaced vertex searches. The collected data during the first physics run using the upgraded detector will be sufficient to explore a significant new region of mass/coupling parameter space.

The landscape of heavy photon searches has changed since 2011. The parameter space that HPS will probe using a displaced vertex search with a 2 GeV to 5 GeV electron beams lies in the most desirable region, but there is stiff competition from other experiments at CERN, FNAL, and elsewhere. Running the remaining of the HPS in a timely fashion is critical to be first to either discover a new force or significantly constrain allowed parameter space for LDM theories.

In this document, we present the current state of the field and the HPS experiment, with the final results of the engineering run, the status of the data analysis of the first physics run, upgraded detector performance, and our plans for future running.

CONTENTS

1. INTRODUCTION

Stepan/John/Tim/Maurik - no more than 1.5 pages

Establishing the nature of Dark Matter is one of the major open challenges of modern physics. The LHC, as well as direct and indirect detection experiments, have significantly constrained one of the best-motivated weak-scale DM models with a class of particle candidates known as weakly interacting massive particles (WIMPs). In contrast, scenarios involving a light hidden sector dark matter with mediators in the MeV-GeV range has garnered a good deal of attention. Models with hidden U(1) gauge symmetry, with a "dark" or "hidden sector" photons, are particularly attractive as they can be tested experimentally. If they exist, heavy photons mix with ordinary photons through kinetic mixing, which induces their weak coupling to electrons, ϵe, where e is the electron charge and $\epsilon \leq 10^{-2}$. Since they couple to electrons, heavy photons are radiated in electron scattering and can subsequently decay into e^+e^-. If ϵ is large enough, $\epsilon^2 \approx 10^{-6}$, they would appear as a narrow mass peak in the e^+e^- invariant mass distribution, which can be observed above the copious QED trident background. For suitably small couplings, $\epsilon^2 < 10^{-8}$, heavy photons travel detectable distances before decaying, providing a second signature. The HPS experiment in Hall-B at JLAB exploits both these signatures to search for heavy photons over a wide range of couplings, $\epsilon^2 > 10^{-10}$, and masses, 20 MeV/c^2 < $M_{A'}$ < 500 MeV/c^2, using a compact, large acceptance forward spectrometer consist of a silicon microstrip vertex tracker (SVT), scintillation hodoscope (SH), and a $PbWO_4$ electromagnetic calorimeter (ECal).

The first HPS proposal was presented to PAC37 in 2011 [1] where it received C2 approval. After the last update to JLAB PAC39 [2] in 2012, where HPS was approved (C1) with an "A" rating, and the decision of PAC41 to grant the 39 PAC days of the HPS beam time out of approved 180 days "High Impact" status, HPS completed two engineering runs in 2015 and 2016 with 1.1 GeV and 2.2 GeV beams, respectively, and run its first physics run in summer of 2019. A small data samples collected during the engineering runs produced our first physics results and became the source of dissertations for six graduate students. Analysis of this data helped to improve our background models, understand our beamline and detectors [3, 4], develop robust analysis techniques, and lead to important upgrades of the detector and the trigger system.

The proposed upgrades have been reviewed and funded by DOE/HEP in FY19. Upgrade to SVT included a new layer, L0, half away between the target and the first SVT layer (L1), to improve vertex resolution, a new thin, slim edge sensors for L0 and L1, and placement of the layers 1 to 3 closer to the beam plane to retain 15 mrad minimum detection angle for e^+s and e^-s from long-lived A' decays. The trigger system was upgraded with a scintillation hodoscope that allowed the implementation of a single-arm positron trigger. The new trigger was needed to recover e^+e^- pairs where the electron misses the ECal while being tracked in SVT. In the first physics run with the upgraded detector, HPS collected about half of the expected data at 4.56 GeV. The detector performance was as expected. The data will be sufficient to explore an uncharted region of mass and coupling using a displaced vertex search method. We expect to release the first physics result from this data in early 2021. After modest repairs, ongoing, the HPS detector will be ready for the next physics run scheduled in the summer of 2021 with a 3.8 GeV electron beam.

The landscape of heavy photon searches has changed a lot since the first HPS proposal. While a significant fraction of parameter space at large ϵ has been ruled out by fixed target and collider experiments, new target regions, motivated by several *hidden sector* scenarios of light dark matter (LDM) [5], have emerged. The parameter space that HPS will probe using a displaced vertex search with a 2 GeV to 5 GeV electron beams lies in the most desirable region. There is stiff competition for the same parameter space from experiments coming online in 2021-2023 at CERN (FASER, SHIP, NA62, LHCb), and FNAL (SeaQuest). Therefore, running HPS is time-critical in order to be first to either discover a new force or significantly constrain allowed parameter space for LDM theories.

In this update, we present the status of the HPS experiment, physics results from the engineering runs and the performance of the upgraded detector during the first physics run. A run plan for the future running beyond 2021 and expected reach are discussed as well. So far HPS used 45.5 PAC days of approved 180 days for the engineering and the first physics runs combined, and expect to use 27.5 PAC days during the schedule 2021 run. With this, we request approval of the remaining 107 PAC days of beam time for HPS, which we plan to use for running with beam energies from 1 GeV to 5 GeV.

2. MOTIVATION FOR DARK PHOTON SEARCHES

Rouven/Philip/Natalia/Tim - No more than 3-pages

Low mass dark matter

Current status of the field

New targets for HPS

3. SUMMARY OF 2015/2016 RUNS

Maurik/Stepan/Matt G/Omar/John - no more than 3 pages

3.1. Engineering run setup and performance

3.2. Physics results

4. FIRST PHYSICS RUN

Stepan/Tim/Maurik - No more than 5 pages

4.1. Upgraded HPS detector

Stepan/Tim/Rafo

Need the technical drawing of the upgraded HPS detector which includes L0 and the Hodo, i.e. the Fig.1 needs to be updated.

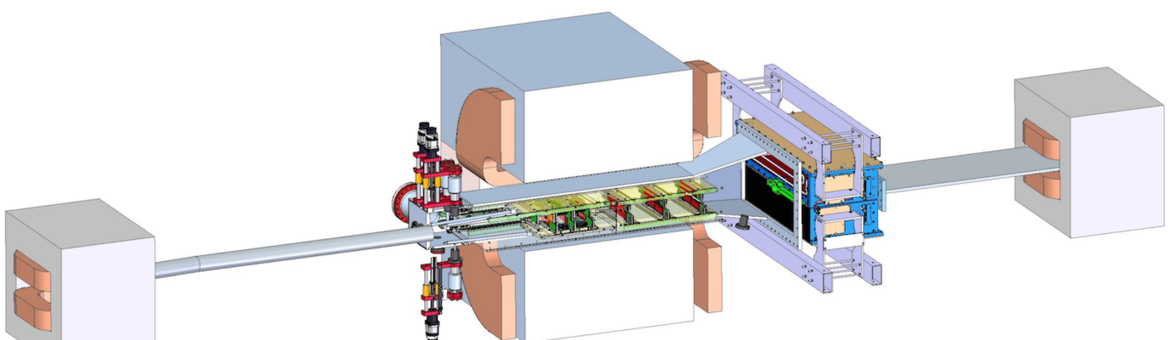

FIG. 1. The engineering design drawing of the upgraded detector.

4.2. Hodoscope

4.2.1. General description of the Hodoscope

The Hodoscope (hodo) is a charge particle detector. It's main purpose is to help to suppress large photon background at the trigger level. Main trigger of HPS will be a coincidence (lateral and time) between hits in Hodoscope and clusters in ECal. The hodo is installed inside the SVT vacuum chamber and is located in between the Layer 6 of HPS SVT and the ECal front face (see Fig.1). The Fig.2 shows the General view of the hodoscope engineering model. Main components

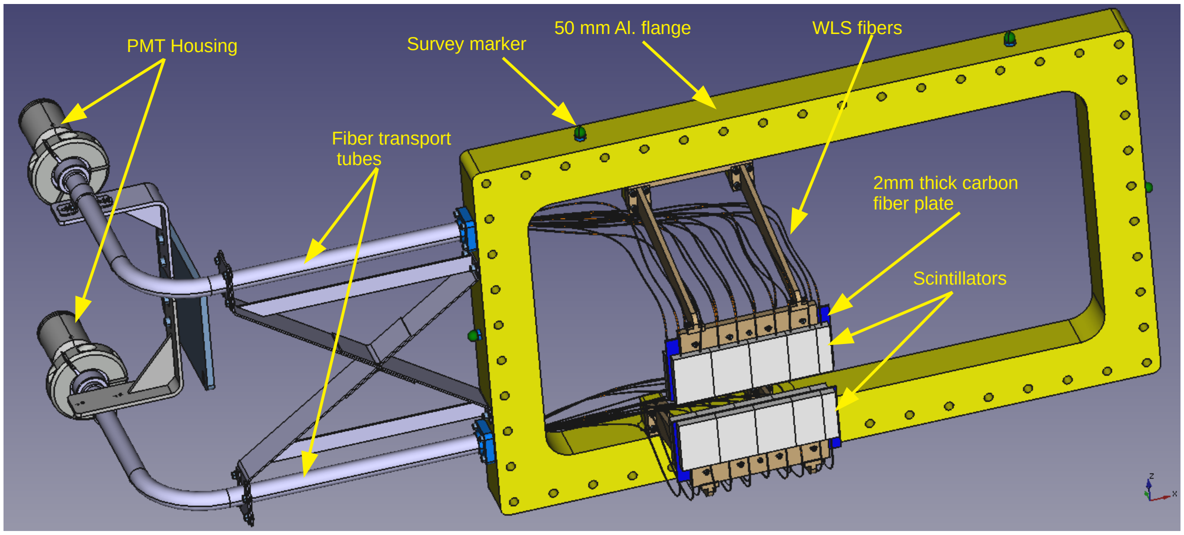

FIG. 2. An engineering drawing of the hodoscope. The picture shows consize description of some parts.

of the hodoscope are described in the picture. Similar to the ECal [3], the hososcope also consist of two identical (mirror to each other) sectors. One is located in the bottom half of the detector, while the other is in the top part of the detector. Each half of the hodoscope consists of two layers of scintillator tiles, and each layer consists of five tiles. These tiles are made from the leftover long scintillators from the CLAS12 Preshower Calorimeter project [3]. The original uncut scintillators had about 5 m length, 45 mm width and 10 mm thickness. Each tile has two holes with a distance d=22.5 mm. For the hodoscope, tiles were cut according to Hodoscope needs. All hodoscope tiles have same hight and thickness which are 60 mm and 10 mm respectively, however some tiles have different widths. The design drawing of tiles are depicted in Fig.3, and the table I shows widths

Tile Coordinate	Width [mm]	Comment
L(1, 1)	15.7	Single hole in the middle
L(1, 2)	34.1	Two holess equal distance from sides
L(2, 1)	19.	Single hole in the middle
L(2, 5)	30.8	Two holess equal distance from sides
The rest of tiles	44	Two holess equal distance from sides

TABLE I. Widths of Hodoscope tiles.

of each tile. Tiles that have widths less than 23 mm, have only one hole which is located at the center of the tile.

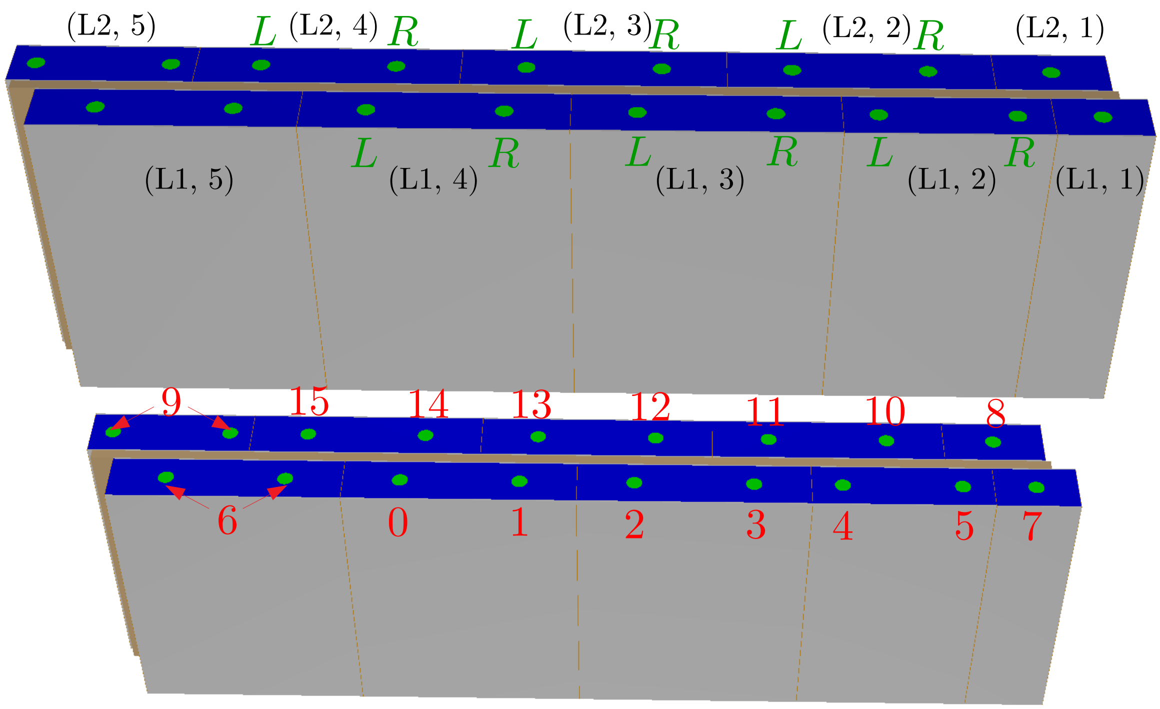

FIG. 3. Schematic representation of hososcope tiles. Numbers in brackets represent tile coordinates: 1st number is is the layer, and the 2nd number describes tile position. Letters in green indicate the hole of the tile. Numbers in Red shows the PMT channel number, for the given fiber bundle

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4.2.2. Hodoscope Readout

The scintillation light is transported to the PMT through through the multiclad 1 mm Kyrary Y11 wavelength shifting fibers (same fibers that was used in CLAS12 preshower calorimeter). Each hole has four fibers except tiles (L1-5) and (L2-5) where each holes has only two layers. All fibers from the same hole goes to a single PMT channel. We have used 4×4 multi anode PMT Hamamatsu H8711-10 [**?**].

4.3. 2019 run

Stepan/Tim/Maurik

4.4. Detector performance

Norman/Cameron/Rafo/Nathan

4.5. Data analysis progress and the expected reach

Matt G./Omar

5. FUTURE RUNNING

Stepan/John/Maurik/Tim - 2 pages

5.1. Upcoming run in 2021 at 3.8 GeV

Detector repairs and modifications

Expected reach

5.2. HPS beyond 2021

Run plan for the remaining beam time, 105 PAC days

Expected reach at all proposed energy settings

6. SUMMARY

[1] A. Grillo *et al.* [HPS Collaboration], HPS Proposal to JLab PAC37 PR-11-006, http://www.jlab.org/exp_prog/PACpage/PAC37/proposals/Proposals/

[2] P. Hansson Andrian *et al.*, [HPS Collaboration], HPS Proposal to JLab PAC39 C12-11-006, https://www.jlab.org/exp_prog/proposals/12/C12-11-006.pdf

[3] I. Balossino et al, The HPS electromagnetic calorimeter, Nucl.Instrum.Meth. A854 (2017) 89-99. arXiv:1610.04319

[4] N. Baltzell et al., The Heavy Photon Search beamline and its performance, Nucl.Instrum.Meth. A859 (2017) 69-75, arXiv:1612.07821

[5] M. Battaglieri *et al.*, arXiv:1707.04591 [hep-ph], 2017.