HPS Upgrade Proposal

HPS collaboration

May 15, 2017

Analysis of the HPS engineering run data showed worse than expected reach in both the bump hunt and the vertexing searches. These reach discrepancies between what we had projected in our proposal and what we measured experimentally were traced to two mistakes that were made in our projections. First, we did not account for the "electron hole" in the ECAL acceptance. Nine modules were removed from the crystal rows nearest to the beam for each of the top and bottom ECAL halves because they suffered very high rates from scattered beam electrons. As it turns out, almost half of the pairs in our rough acceptance have the electron ending up in that hole, so they have been missing in our nominal trigger. Our pairs-1 trigger requires a coincidence of two clusters, one in each of the top and bottom ECAL. The second mistake was that we had assumed constant efficiencies for decay lengths out to 10 cm for electron-positron pair detection. The fall-off in efficiency for decays that occur more than 3 cm downstream of the target had not been properly accounted for. In order to mitigate these losses in our reach, two modest upgrades to the existing HPS setup are proposed.

1 Tracking efficiency and vertexing improvements

The HPS SVT was constructed with vertical acceptance beginning at 15 mrad above and below the beam plane in all layers with respect to the target at z=0, limited by backgrounds from beam scattering in the target which exceed 1 MHz/mm^2 in Layer 1 at z=10 cm. However, for decays that occur significantly downstream of the target, the angular acceptance is considerably less. For example, a particle originating at z=10 cm must have a vertical angle of 30 mrad with respect to the beam to hit Layer 2 at z=20 cm. For simplicity, the proposal assumed that the total acceptance could be approximated by assuming the acceptance for particles originating at z=0 for all decays originating before Layer 1, 10 cm downstream of the target. This overestimated the number of A′ decays that would fall within the SVT acceptance, especially for low A′ masses that favor smaller opening angles.

Even before this error was realized, HPS was considering a proposal to add another layer to the SVT at z=5 cm to improve the reach of the experiment. This "Layer 0" uses thin silicon to achieve half the material budget, and being placed half the distance to the target improves the vertex resolution by at least a factor of two, allowing sensitivity to shorter decays. Since exponentially-decaying A′ naturally produce larger yields at shorter decay lengths than at longer ones, this change dramatically increases the final signal yields for the vertexing analysis over a broad range of parameter space. In order to deal with larger occupancies and keep S/N constant for thinner silicon, shorter strips are used. In order to allow the active silicon closer to the beam without putting the edge of the sensor closer to the beam, slim-edge processing is used to reduce the width of the dead silicon along the edge facing the beam. With a slim edge of less than 200 microns, the clearance between Layer 0 and the beam will be slightly larger than for Layer 1. Full simulation of the upgraded detector shows that the addition of Layer 0 improves the vertex resolution and event yields as expected, as shown in Figure 1. Figure 2 shows the increase in the signal yield from the addition of Layer 0 in the heart of the vertexing reach for the nominal detector. With Layer 0, the running time to reach the same area in the parameter space of the vertexing search is cut by more than a factor of two.

The flexible and modular design of the HPS SVT makes the addition of Layer 0 relatively simple. The modules of the detector derive their cooling from being mounted on a cooled aluminum structure, which is easily extracted from the detector without removing the entire SVT and easily modified to accommodate new modules for Layer 0. More importantly, there is spare DAQ capacity in the as-built SVT, from connections where the modules will be located all the way to the off-detector RCE DAQ, to read out the modules of Layer 0. From a hardware standpoint, the DAQ is "plug and play" with only new firmware required to read out the upgraded detector. To upgrade the detector, the supports that hold Layers 1-3 will be extracted and shipped back to SLAC. The modules will be removed and the blocks that currently hold the SVT scan wires upstream of Layer 1 will be replaced

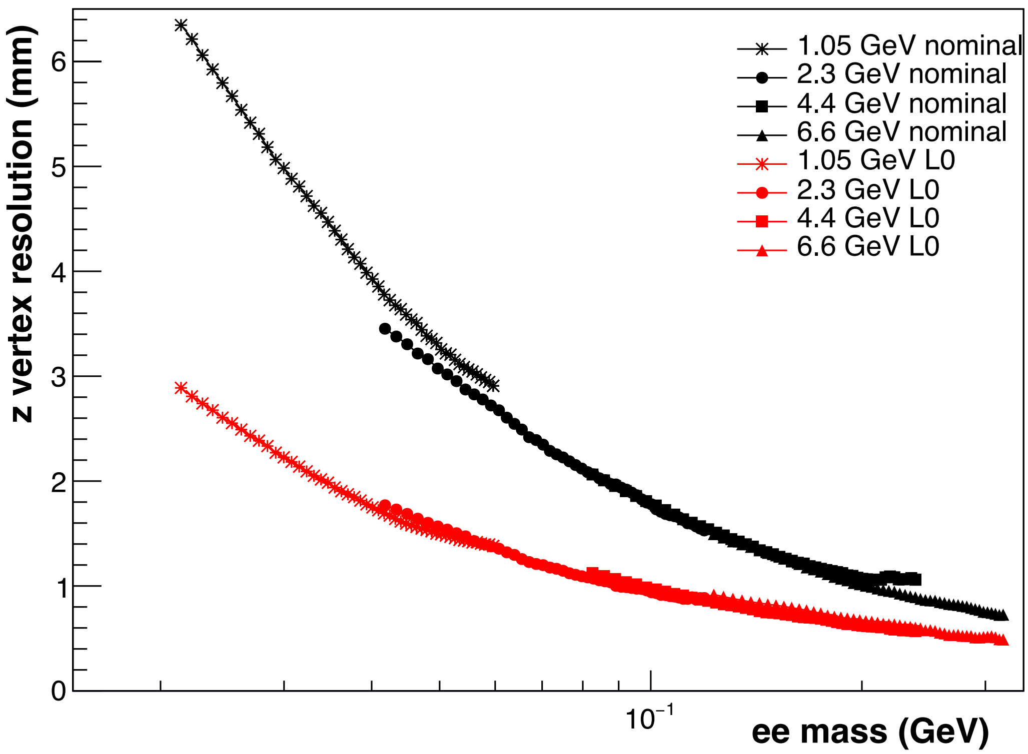

Figure 1: The z-vertex resolution of the nominal and upgraded SVT as a function of A′ mass and at different beam energies.

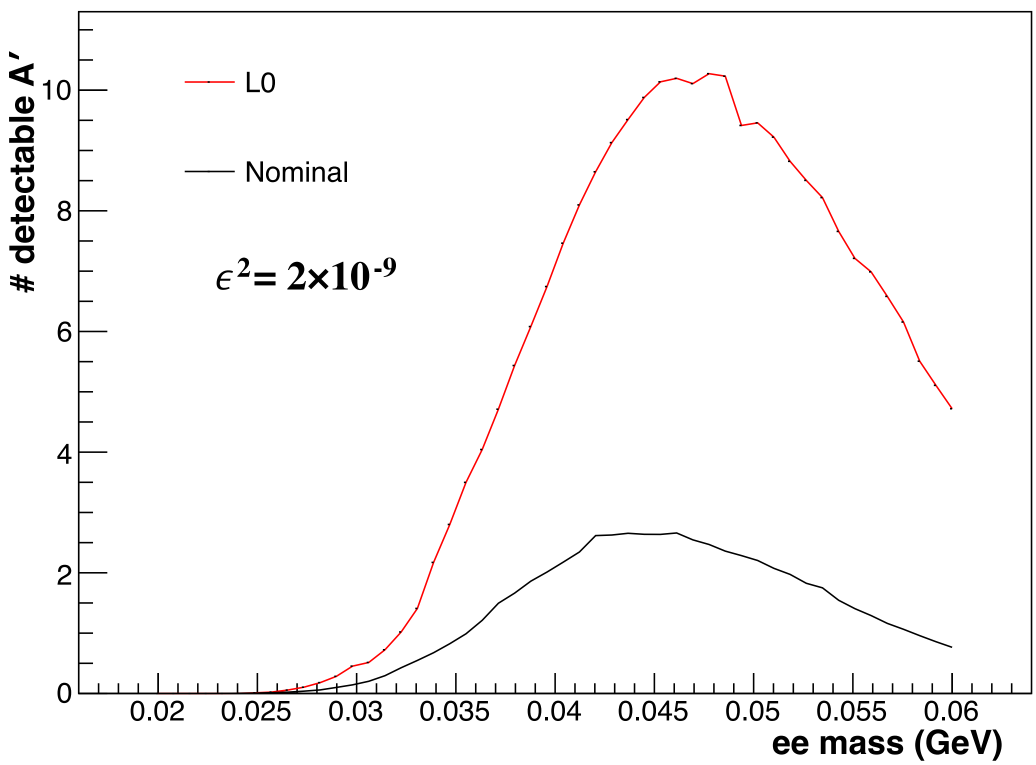

Figure 2: The expected signal yield of A′ events as a function of mass at a coupling in the heart of the vertexing reach for the nominal detector, after all selections including a cut on z vertex position that eliminates all but 0.5 events of background. Since this cut for the upgraded detector can be much tighter, the number of "detectable" events is much larger.

by new longer blocks that hold both Layer 0 and the repositioned scan wires. The technologies and design of the hybrids and sensors are identical to those used in the current SVT.

Because the Layer 2 and Layer 3 modules will be removed during the process of the Layer 0 upgrade, there is the additional opportunity to adjust the positions of Layers 2 and 3 to improve their acceptance for long-lived A′ decays. While Layer 0 cannot be moved closer to the beam, the occupancy in other layers is lower. Moving the rest of the detector inwards towards the beam by 1.5 mm would give 15 mrad acceptance for all decays from 0 to 10 cm downstream of the target as assumed in the proposal. Studies show that Layer 2 may only be moved inward about half that much, 750 μm, before occupancy becomes a problem, but moving Layers 2 and 3 inward by this small amount recovers about half of the lost acceptance. The move can easily be accomplished with the installation of thin shims when remounting Layers 2 and 3 on the support structure.

2 Positron only trigger

A simple way to recover events where the electron is lost in the ECAL hole is to trigger and do track-ECAL matching only for positrons. The electron will still be caught in the acceptance of the SVT, and tracked. In the HPS setup positrons from the reactions of interest will hit the ECAL in a well-defined region, $x_{ECAL} > 100$ mm in the HPS coordinate system, called the *positron region*. From analysis of the *random trigger* data, we measured $\sim 10-12$ kHz rate for positrons in this region of the ECAL. Unfortunately this region is also populated by photons from wide-angle bremsstrahlung (WAB) which have an order of magnitude higher rate than positrons. In fact, 2/3 of the main pairs-1 triggers for the data taking come from WAB events, $(e^{-}\gamma)$ pairs. To differentiate between photons and positrons a charged particle detector is needed in the trigger. We propose to use a scintillation counter in front of the ECAL in the *positron region* to ensure the ECAL cluster is associated with a charged particle. Putting the scintillator in coincidence with the ECAL clusters in the trigger provides a single arm positron trigger.

From engineering run data we know that the rates in the ECAL modules in the *positron region* are very low, see Fig.3. The *positron region* extends from the module #4 to the right, and the total rate for that region is < 300 kHz. In order to test the idea of using the coincidence between a scintillation counter and the ECAL in the trigger, we studied the rate of 3D hits in L6 of the SVT, as a proxy for the scintillation counter. The correlation of the SVT L6 hit positions with those of the clusters in the ECAL *positron region*, $x > 100$ mm, is shown in Fig.4. The same *random trigger* events were used. A clear correlation is seen in both the x- and y-distributions. The rate in SVT L6 for the region corresponding to the *positron region* in the ECAL was estimated to be ~ 150 kHz, quite manageable for a scintillation counter with PMT readout. The coincidence rate of correlated SVT hits and ECal clusters is ~ 15 kHz , close to what was estimated using the positron tracks (see above).

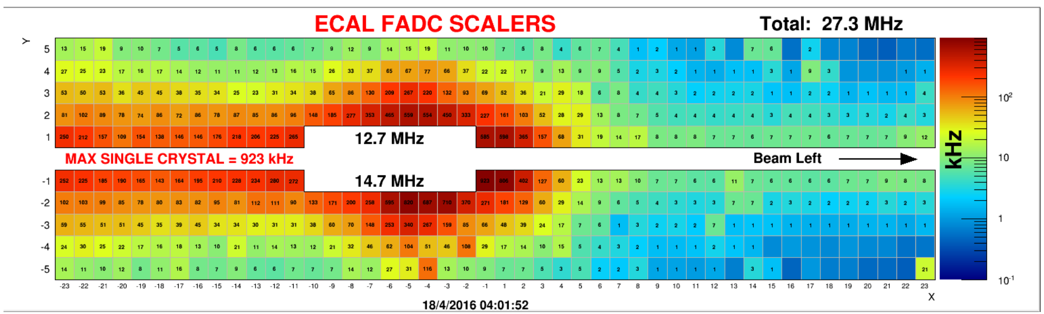

Figure 3: The ECAL FADC scaler screen from 2016 engineering run with $E = 2.3$ GeV beam energy.

The detector concept is based on a scintillator hodoscope, comprised of pixels with embedded wave-length shifting fibers, read out using a multi-anode PMT. The ECAL is mounted very close to the HPS vacuum chamber exit flange, so there is no space to install the hodoscope between the ECAL and the vacuum chamber. The ECAL cannot be moved away from the flange due to mechanical constraints from the ECAL vacuum chamber. Besides, the $0.5''$ thick vacuum chamber window can be a source of conversions from WAB photons, which would give a signal in the scintillation counter. For these reasons we plan to mount the pixel counter inside the vacuum chamber, roughly halfway between the SVT L6 and the flange. The photodetectors, multi-anode PMTs, will be located outside of the vacuum, and mounted on a vacuum feedthrough for the fibers. Such a configuration has worked well for the CLAS beam offset monitor for many years. For the scintillator light collection using the fibers, we will use the same concept that was used for

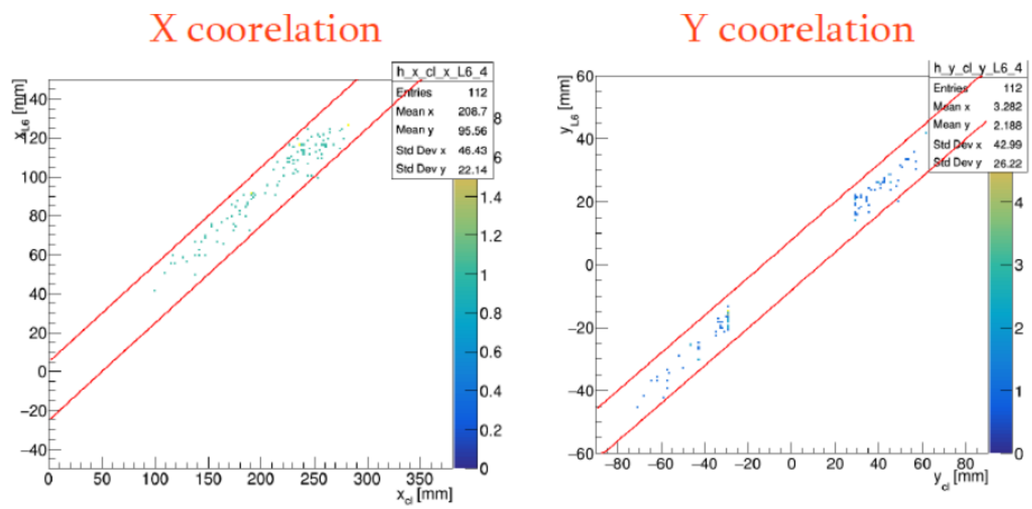

Figure 4: The x- and y-correlations between hit position in the L6 SVT and the cluster position in ECAL.

the CLAS12 PCAL. Currently, full GEANT-4 simulations are underway to finalize the exact position and the number of pixels needed for the scintillation detector. Based on the expected rates, we imagine this to be a 16 channel scintillation hodoscope for each of the top and bottom halves of the HPS detector. We will need 2 multi-anode, 16 channel PMTs (Hamamatsu 8711) and 2 JLAB FADCs to read out signals from the PMTs. Changes to the trigger firmware will be very minor. The existing trigger already has a "single arm" trigger setup that has been used during the engineering run (with a large prescale factor). Modification will be needed to correlate clusters from the *positron region* of the ECAL with relevant signals from the hodoscope. Recall that the cluster position is available at the trigger level and has been used in the existing pairs-1 trigger, so this is expected to be straightforward.