Inclusion of Hit-timing Information in HPS Track Reconstruction

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The Heavy Photon Search is an experiment aimed at discovering a hidden-sector, heavy photon. Key to the experiment is the ability to run a silicon vertex tracker in the high-background environment downstream of a target hit by an intense electron beam. We plan to accomplish this using the continuous duty cycle of the CEBAF accelerator at Jefferson Lab, combined with time reconstruction of hits in the silicon microstrips to discard hits with times too far removed from the trigger time. Data from a parasitic test run shows that we can obtain time resolution of $\sigma_t = 3$ ns, with expected improvement to 2 ns; this will allow us to apply a hit time window of 8 ns as required for the full experiment.

Tracker Requirements

HPS uses an electromagnetic calorimeter to generate triggers with 4ns time resolution and trigger rates up to 50 kHz. A silicon microstrip tracker is used for momentum measurement and vertexing, both of which are critical to A' identification.
The test run tracker is made up of five measurement layers (six in the full experiment), each containing a stereo pair of two closely spaced planes of silicon microstrip sensors to measure both X and Y coordinates for momentum measurement and track identification.

Figure 1: *Rendering of the HPS test run tracker.*

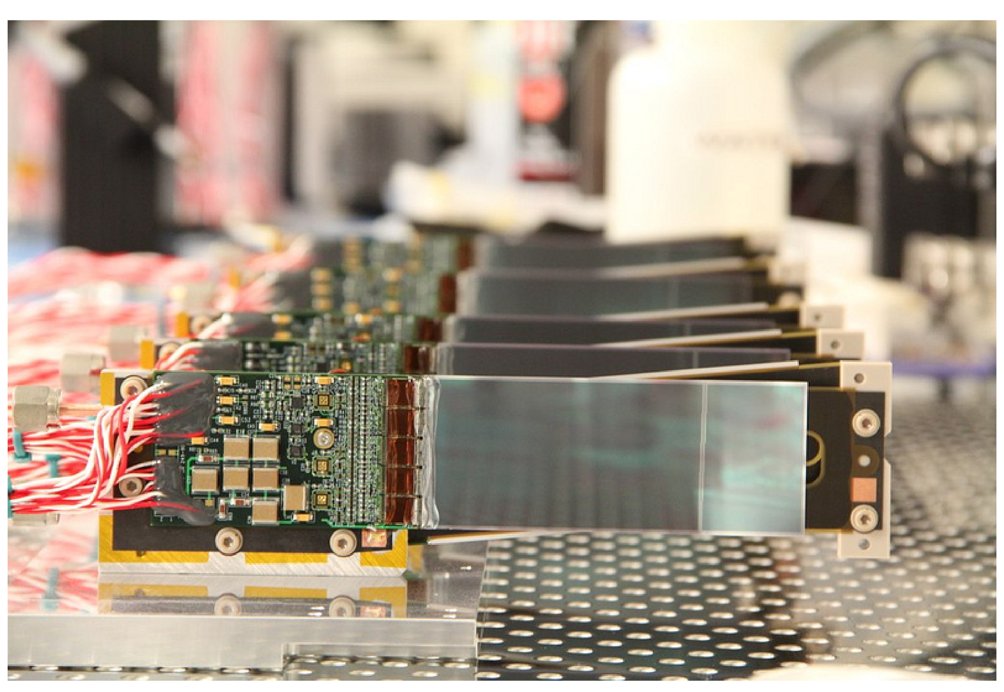

Figure 2: *Bottom half of the HPS test run tracker. The APV25 readout chips are visible at the left end of the sensor.*

Scattered beam electrons create a "sheet of flame" in the bending plane of the magnetic field. The tracker is split in two halves above and below this region, but the edges of the tracker still see very high background rates.
For good tracking performance, the tracker occupancy must be held below 1%; this sets the minimum distance between the sensors and the beam. The HPS proposal assumes that tracker hit times can be assigned to 8 ns windows without significant loss of efficiency. This puts layer 1 of the tracker at 1.5 mm from the beam.

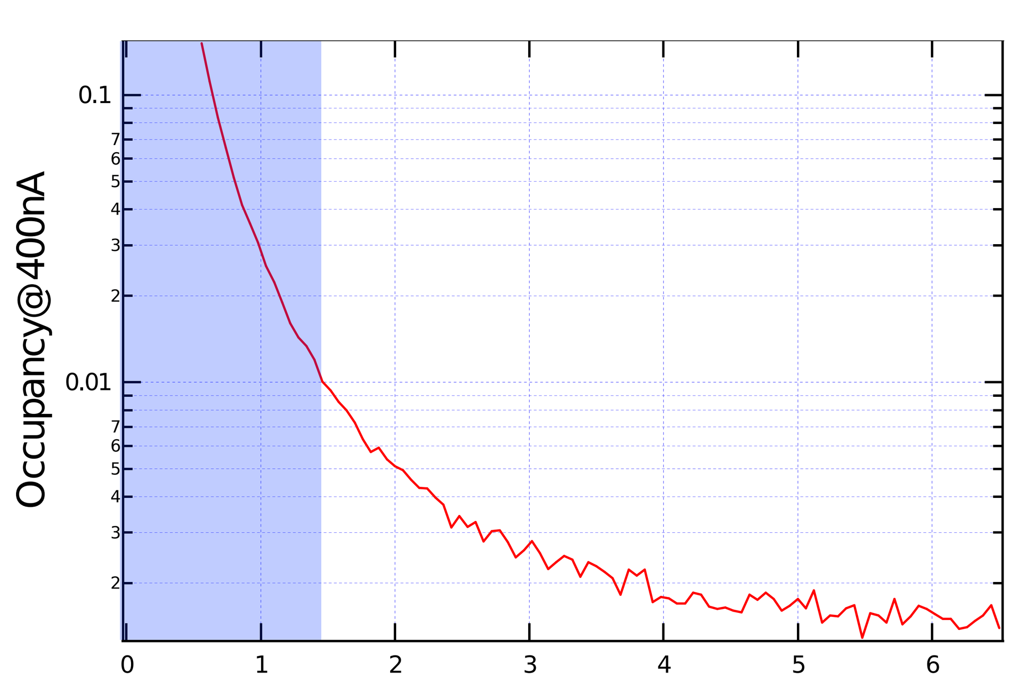

Figure 3: *Strip occupancy in the first layer as a function of distance from the beam plane, for 400 nA beam (as expected for the full run) and an 8 ns time window. Blue highlight marks the "dead zone" of excessive occupancy.*

APV25 Readout and Hit Reconstruction

We read out the microstrips using the APV25 chip developed for the CMS tracker at the LHC. The APV25 preamplifier and shaper produce a CR-RC shaping curve with a shaping time T_p which for the test run was set at 50 ns (35 ns in the full run).
The APV25 samples the shaper output once per clock cycle (24 ns for HPS), and in "multi-peak" mode, outputs 3 consecutive samples per trigger request. HPS reads out 6 samples for each trigger. The samples are fit to the pulse shape to find the hit time relative to the APV25 clock.

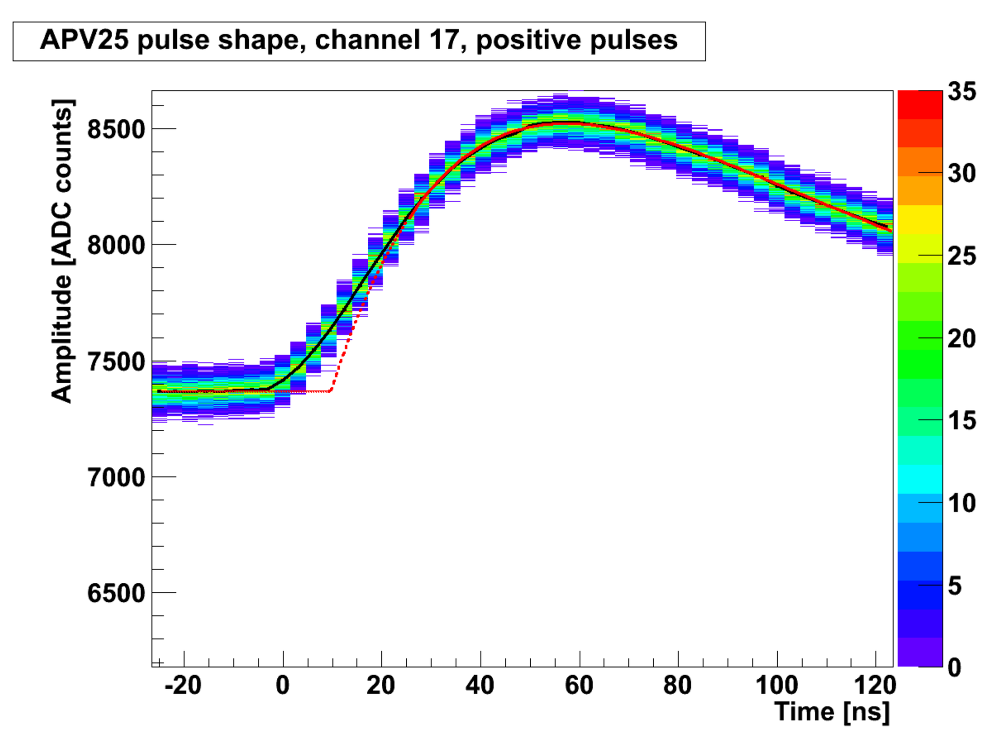

Figure 4: *APV25 shaping curve as measured using internal calibration circuit. Black curve is the measured pulse shape; red curve is the best-fit CR-RC pulse shape.*

Adjacent strip hits are clustered to form tracker hits. The amplitude of the tracker hit, corresponding to charge deposition in the sensor, is the sum of the strip hit amplitudes. The time of the tracker hit is the mean of the strip hit times, weighted by hit amplitude.

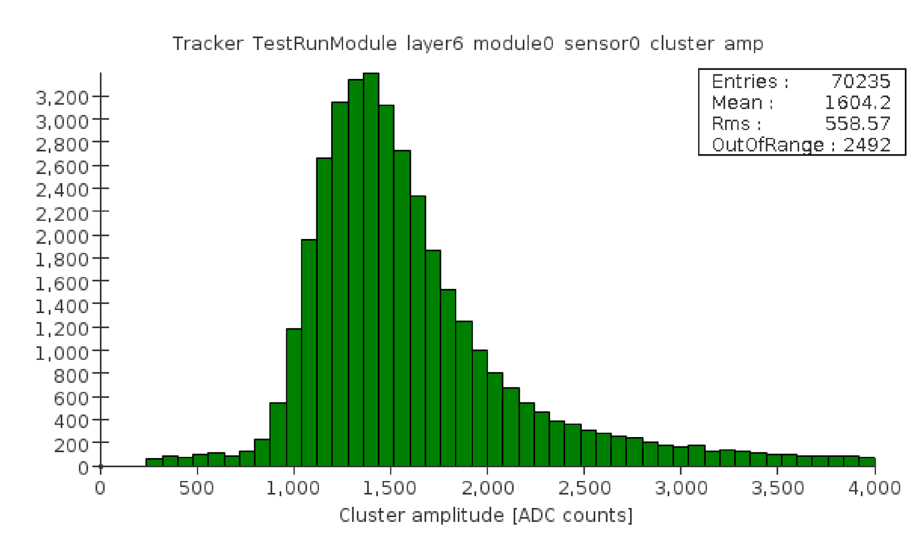

Figure 5: *The distribution of amplitudes of clustered tracker hits follows a Landau distribution peaked at 1400 ADC counts, as expected from sensor specifications.*

Currently, tracks are fitted to all tracker hits in an event regardless of hit times. The mean of hit times in a track is taken as the "track time."

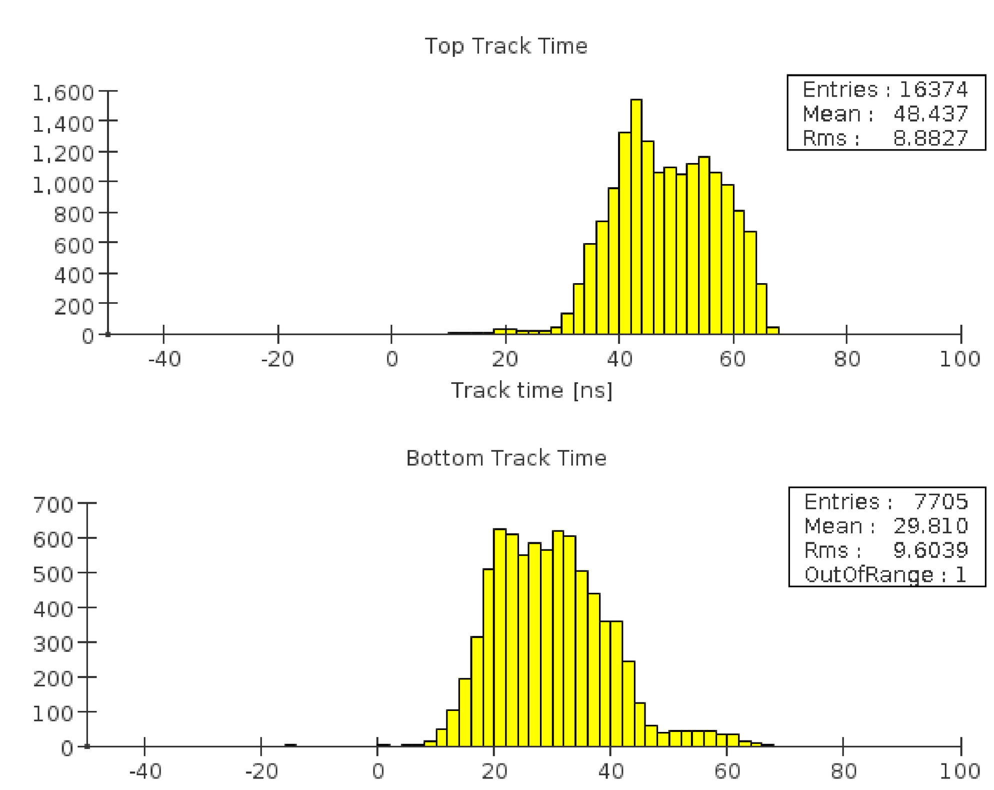

Figure 6: *Track time distribution, measured relative to the APV25 clock, for top and bottom tracks. The width of the distribution is due to trigger jitter (24 ns jitter in tracker readout clock, plus 16 ns jitter in the trigger system). The shift between top and bottom is due to a trigger time shift between the two halves of the ECal.*

Taking the residual of the hit times relative to the track time gives an estimate of the hit time resolution σ_t. We see σ_t of better than 3 ns. A more sophisticated pulse fitter has shown time resolution of 1.5 ns in benchtop tests, and work is ongoing to apply this fitter to the test run data. Reducing the APV25 shaping time is also expected to significantly improve time resolution.

Histogram Tracking and Time Cut

For the full experiment, hit times must be used to preselect sets of tracker hits for track reconstruction. We plan to do this using the "histogram tracking" technique originally developed for track reconstruction at CDF. As applied to our situation, histogram tracking finds the most likely track time and then finds all the hits passing a cut relative to the track time; these hits can then be passed to our track reconstruction algorithm.

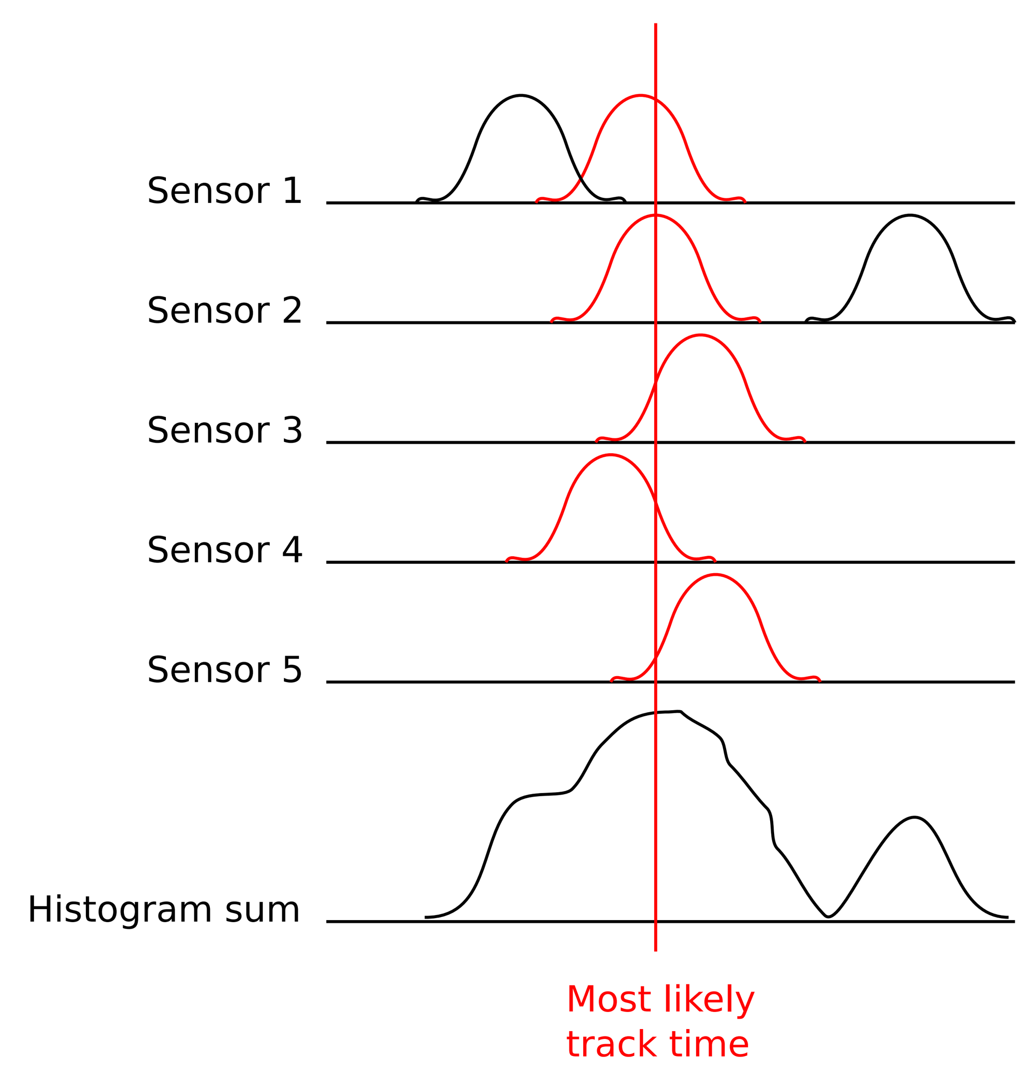

Figure 7: *Histogram tracking efficiently finds the track time with maximum likelihood. Hits passing a timing cut are then used for track fitting.*

The size of the time cut must be chosen to optimize efficiency; too tight a time cut will eliminate valid tracks, and too loose a time cut will raise our occupancy. We can look at our tracks — made without any time cut — to measure the efficiency of any time cut. We see that a time window of 12 ns would lead to 90% efficiency (10% of tracks would lose at least one hit). Many of the tracks that fail this cut would still retain enough hits for correct track reconstruction. The expected improvements in time resolution will also improve the time cut efficiency, and we are confident that we can demonstrate the expected performance.

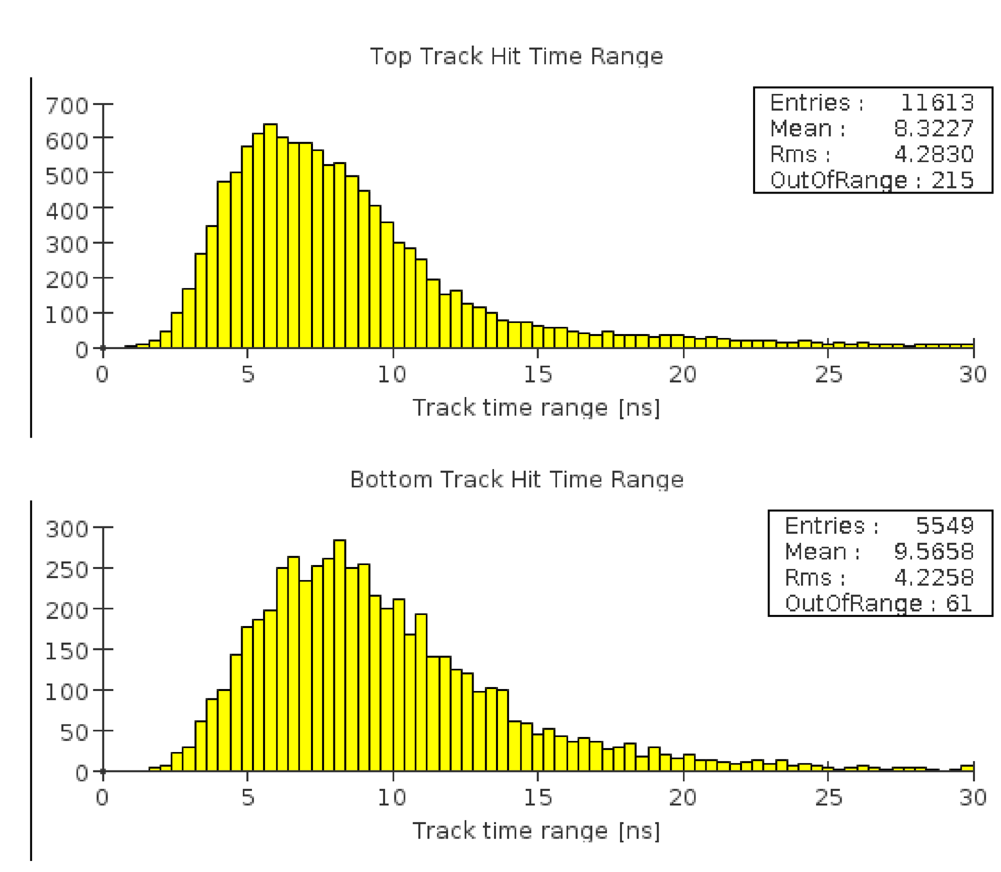

Figure 8: *Time difference between the first and last hit in each track. A basic timing cut would only fit tracks to hits falling within a fixed-size time window.*