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Title: Eight Pulse Performance of DARHT Axis II - Preliminary Results

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# Eight Pulse Performance of DARHT Axis II – Preliminary Results

**Abstract**

The DARHT-II accelerator produces a 1.65-kA, 17-MeV beam in a 1600-ns pulse. Standard operation of the DARHT Axis II accelerator involves extracting four short pulses from the 1.6 us long macro-pulse produced by the LIA. The four short pulses are extracted using a fast kicker in combination with a quadrupole septum magnet [1] and then transported for several meters to a high Z material target for conversion to x-rays for radiography. The ability of the DARHT Axis 2 kicker to produce more than the standard four pulse format has been previously demonstrated [2]. This capability was developed to study potential risks associated with beam transport during an initial commissioning phase at low energy (8 MeV) and low current (1.0 kA).The ability of the kicker to deliver more than four pulses to the target has been realized for many years. This note describes the initial results demonstrating this capability.

## Kicker Performance without Beam

Prior to beam studies, the kicker software was tested and successfully demonstrated multi-pulse capability with and without high voltage. Figure 1 shows the positive and negative kicker voltage waveforms for fourteen 12 ns pulses with 100 ns spacing (head-to-head). This result suggests the possibility of 16 pulses over the 1.6 us Axis 2 beam pulse. The green trace show the difference between the positive and negative voltage waveforms and suggests a possible issue with the positive waveform generator. Figure 2 show similar features for sixteen 12 ns pulses separated by 140 ns. Figure 3 shows eight 20 ns pulses separated by 250 ns. In this case the difference between the positive and negative traces is much lower. Figures 1-3 are from studies performed in March 2011. Recent studies made in July 2015 show similar capabilities as shown in Figure 4. Here a single 20 ns pulse is followed by seven 28 ns pulses. The expected voltage and pulse length modulation was also demonstrated. This pulse format was used for initial beam studies.

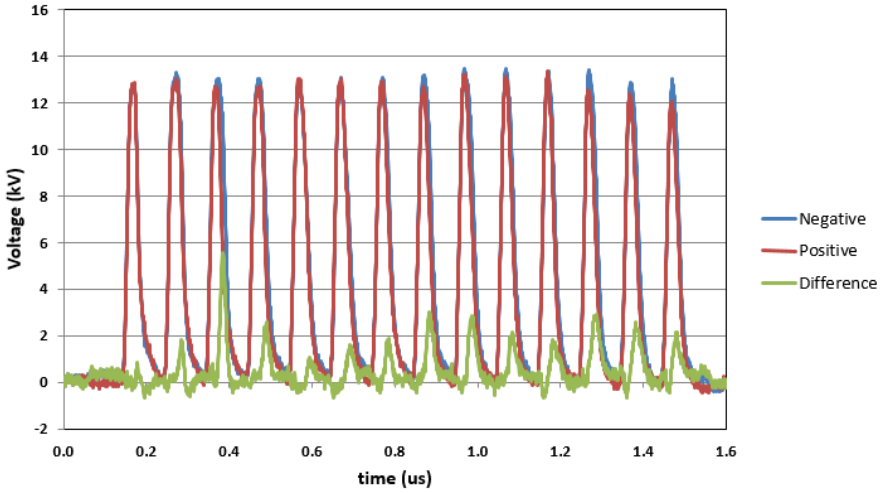


Figure 1: Fourteen 12 ns pulses with 100 ns spacing

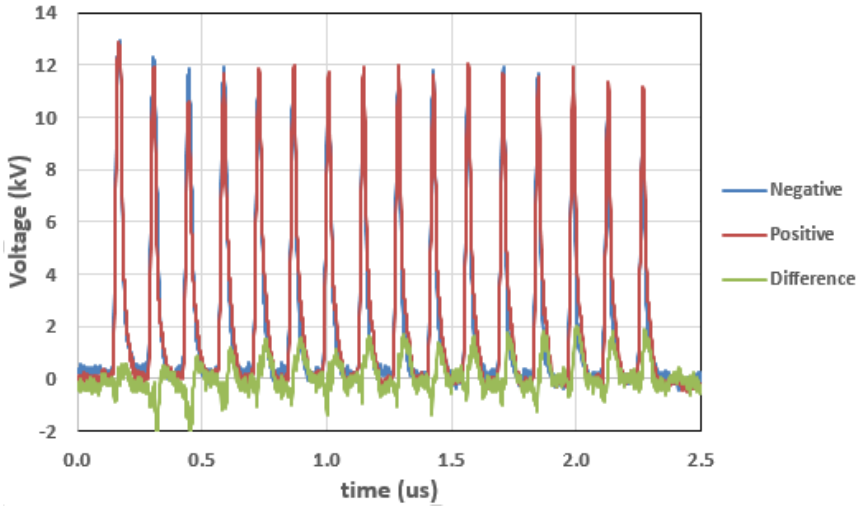


Figure 2: Sixteen 12 ns pulses with 140 ns spacing

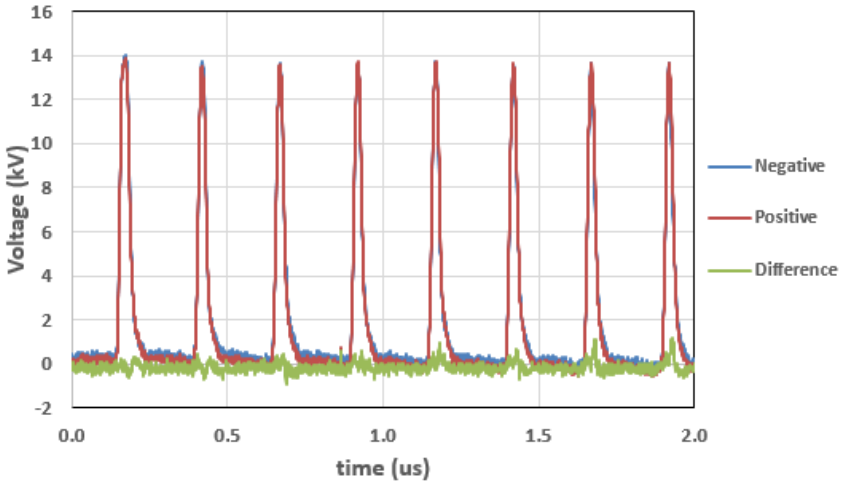


Figure 3: Eight 20 ns pulses with 250 ns spacing

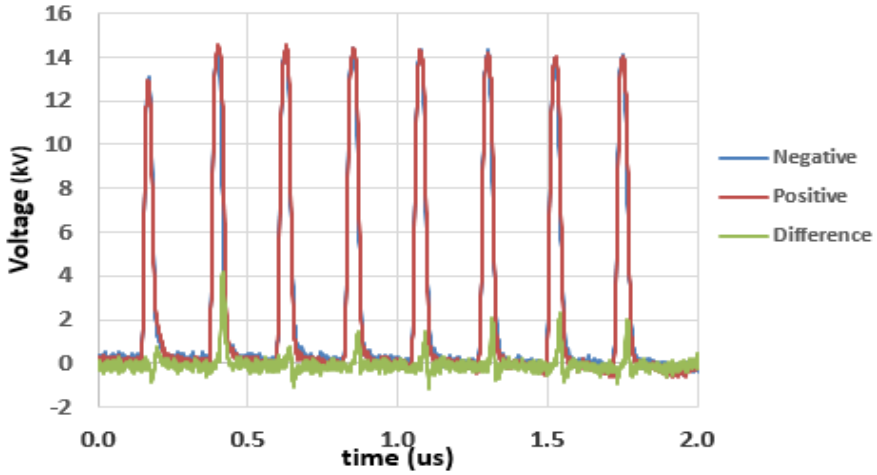


Figure 4: Eight pulses with 225 ns spacing. The P1 pulse width is 20 ns and P2-P8 are 28 ns.

**Downstream Transport Tune**

The initial settings for all focusing magnets in the accelerator and downstream transport (DST) were identical to those used in hydrotest 3667 with the exception of the final focus magnet. Hydrotest 3667 was fired a week prior to multi-pulse beam studies and was a very low dose shot. There were several changes to the steering and kicker voltage settings for the individual pulses.

Once the injector was extended to full pulse length, steering, kicker voltage and energy adjustments were made to center the beam. The beam was then focused on target with P6, P7 and P8 turned off in order to verify that target density retention was maintained. This was done by measuring the dose per pulse and verifying that the dose was not decreasing for later pulses. P6, P7 and P8 were then turned on in three successive shots and no significant reduction is dose was observed. The pulse format was the same as that shown in Figure 4. The beam energy was increased for P6-P8 by adjusting the timing of cell 74 in order to reduce the beam motion at BPM30.

Figure 5 shows the beam energy and timing of the pulses for the first eight pulse focused shot on target (shot 27599). Figures 6 and 7 show the horizontal and vertical beam position for the eight pulses at BPM30 which is located just upstream of the final focus magnet. The beam position is plotted for all times in which the measured beam current was above 900 A. The beam motion seen in Figures 6 and 7 results from the rise and fall of the kicker and is referred to as kicker smear.

Additional studies were performed to optimize the measured spot sizes with longer pulse lengths of 40 ns for P4-P8. Adjustments were made to the timing of the last three accelerator cells to optimize the spots. Figures 8 and 9 show the measured horizontal and vertical beam position at BPM30. Figure 10 shows the beam energy for this shot (27696) as well as Shot 27599 and the 3667 tune. A comparison of the kicker smear at BPM30 shows that the reduced energy in the first half of the beam pulse resulted in a significant reduction in the kicker smear for the first four pulses. No focusing magnets were changed with the exception of the final focus which is located after BPM30. This shows the strong sensitivity of the kicker smear to the beam energy and magnet tune. An overlay of the kicked beam current (blue) with the injector current (black) and the measured current at the accelerator exit (red) for shot 27696 is shown in Figure 11.

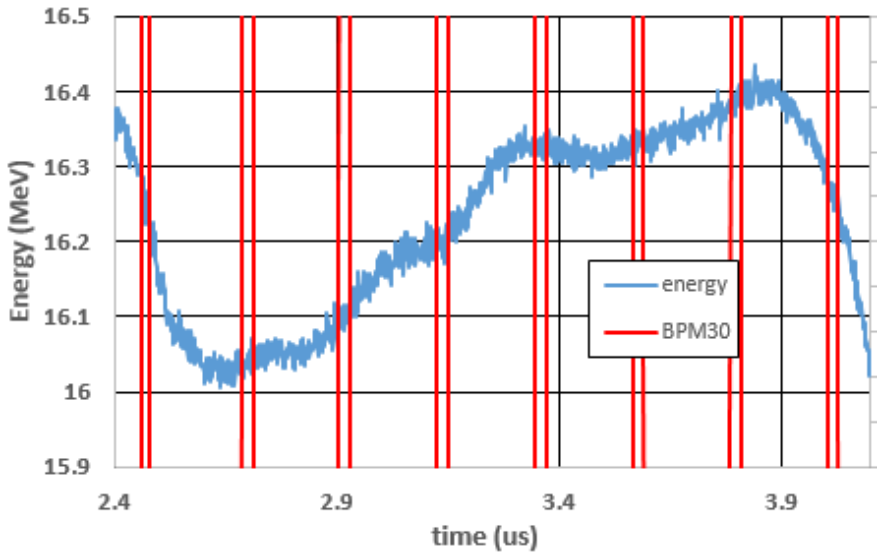

Figure 5: Beam energy and timing of the first eight pulse focused shot on target (shot 27599)

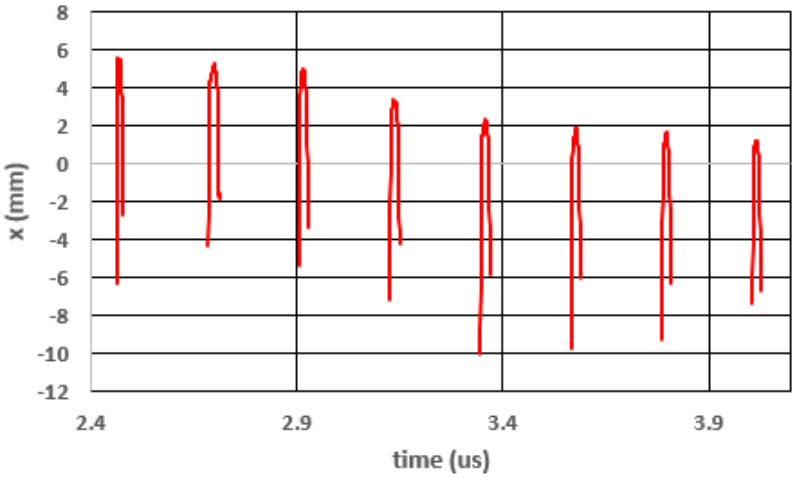

Figure 6: Horizontal position at BPM30 the first eight pulse focused shot on target (shot 27599)

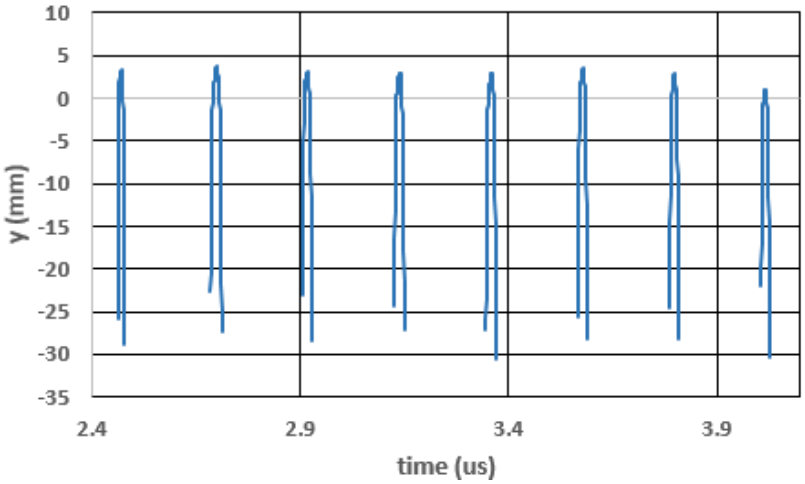

Figure 7: Vertical position at BPM30 the first eight pulse focused shot on target (shot 27599)

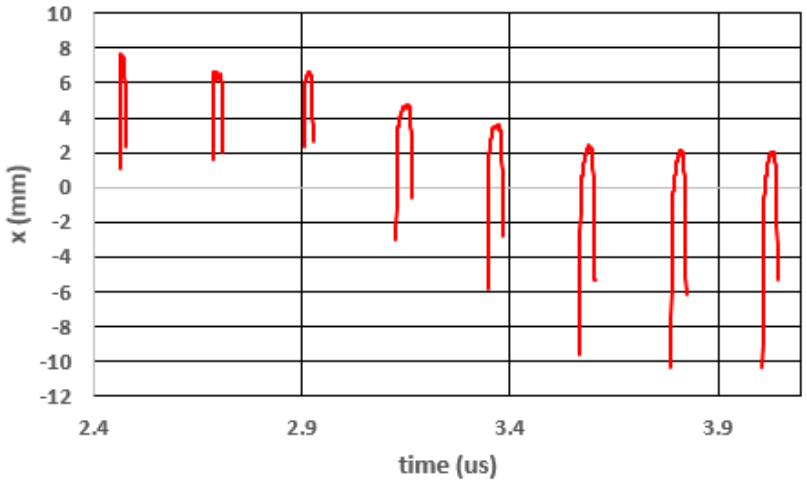

Figure 8: Horizontal position at BPM30 for shot 27696.

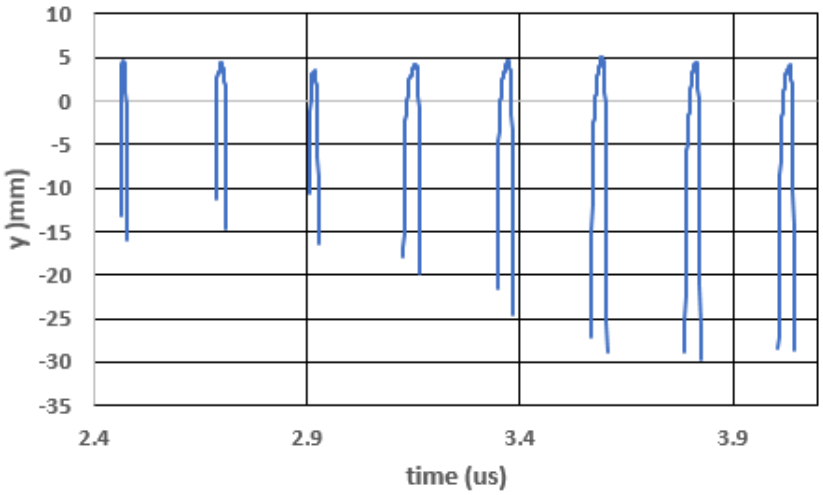

Figure 9: Vertical position at BPM30 for shot 27696.

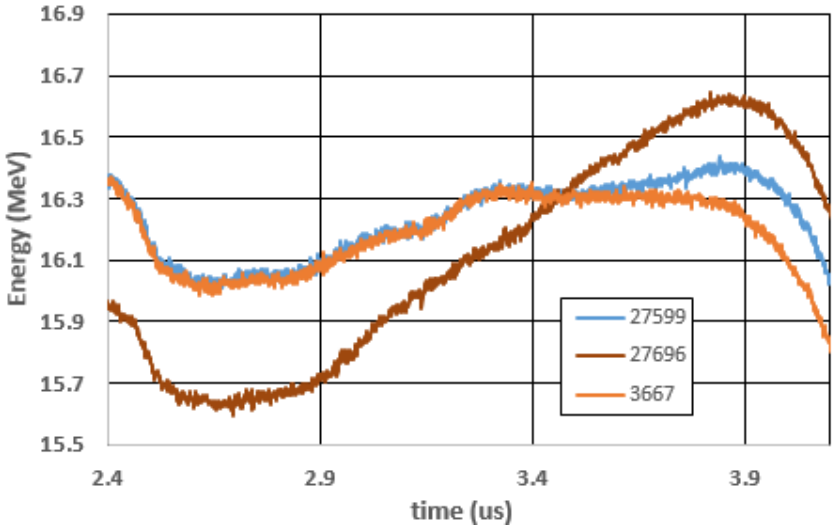

Figure 10: Beam energy for shots 27599, 27696 and 3667.

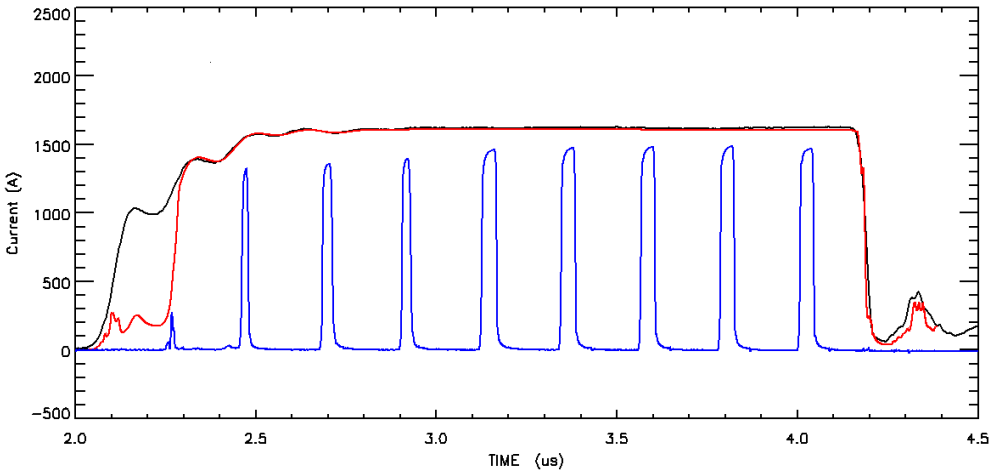

Figure 11: Overlay of the kicked beam current (blue) with the injector current (black) and the measured current at the accelerator exit (red) for shot 27696.

**Spot Size and Dose at Target**

In order to obtain distinct images of the spot size of the eight pulses, the gamma-ray cameras (GRC) were configured differently from normal four pulse operation. The center camera was configured so that the four frames captured P1 and P2, P3 and P4, P5 and P6, and P7 and P8 respectively. The timing of two of the outer cameras was adjusted to see a single pulse. Using this approach and repeating shots, spot size information was obtained for all eight pulses.

Figure 12 shows the measured spot sizes of the eight pulses for shot 27599. The left hand image is the sum of P1 and P2 and subsequent images from left to right show P3 and P4, P5 and P6 and P7 and P8 respectively. The final focus was set to 472A. The beam spot sizes were all between 1.2 and 2.0 mm (50%MTF) and the relative positions of the eight pulses on target were within a 0.30 mm radius. In general, the spot size increased for the later pulses. The typical dose per pulse was about 82 R for P1, 122R for P2 and about 110R for pulses P3-P8. The target was the standard high dose target employed for four pulse operation. This also demonstrates the shortest inter-pulse spacing for a focused beam on target of 200 ns with very good spot sizes.

Figure 13 shows the measured spot sizes of the eight pulses for shot 27689. The left hand image is the sum of P1 and P2 and subsequent images from left to right show P3 and P4, P5 and P6 and P7 and P8 respectively. The final focus was set to 464A reflecting the lower energy of the first four pulses. The beam spot sizes were all between 1.2 and 1.85 mm (50%MTF) and the relative positions of the eight pulses on target were within a 0.45 mm radius. In general, the spot size increased for the later pulses. The average FWHM, dose and pulse length are presented in Table 1. The total dose was measured to be 1150R at 1m. This is higher than the highest four pulse dose achieved of 1100R at 1m. The sum of the eight kicker pulse lengths was 276 ns compared to the highest four pulse total kick of 282 ns.

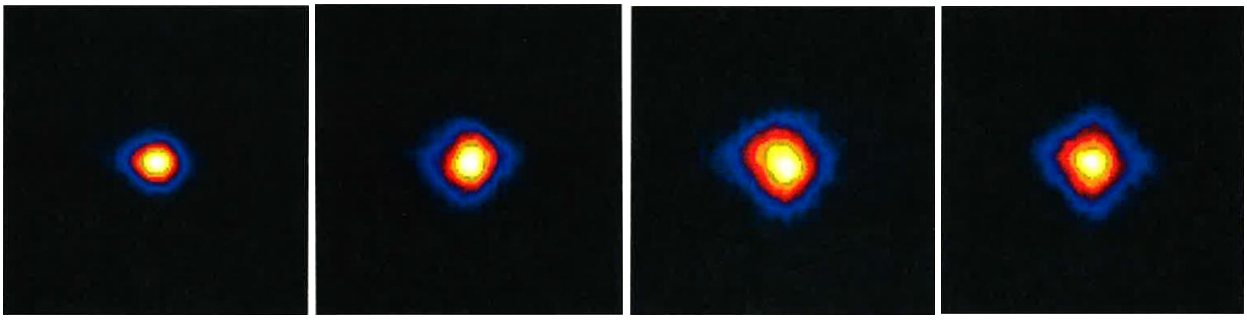

Figure 12: Measured spot sizes of the eight pulses for the first 8-pulse focused shot on target (Shot 27599). The left hand image is the sum of P1 and P2 and subsequent images from left to right show P3 and P4, P5 and P6, and P7 and P8 respectively

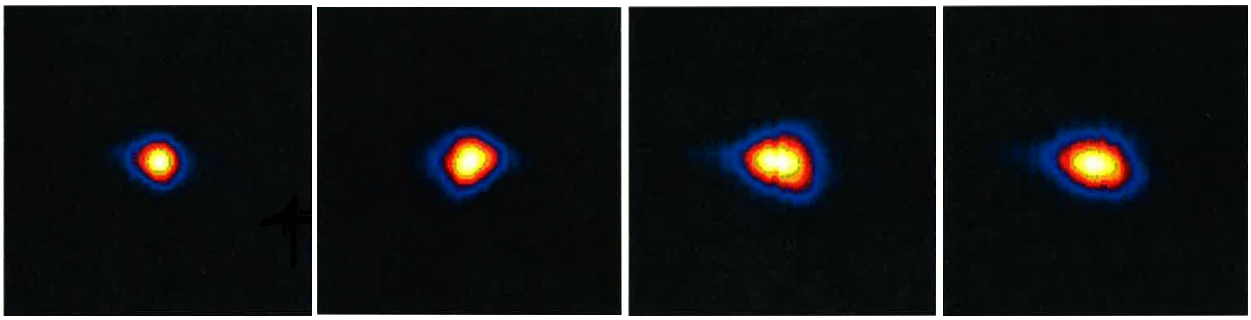

Figure 13: Measured spot sizes of the eight pulses for a higher dose 8-pulse focused shot on target (Shot 27689). The left hand image is the sum of P1 and P2 and subsequent images from left to right show P3 and P4, P5 and P6, and P7 and P8 respectively

Table 1: Pulse length, dose and spot size for shot 27689

| Shot 27689 | Pulse Length (ns) | Dose (R @ 1m) | Spot Size FWHM (mm) |
|---|---|---|---|
| P1 | 20 | 76.4 | 0.66 |
| P2 | 28 | 117.5 | 0.77 |
| P3 | 28 | 100.2 | 0.83 |
| P4 | 40 | 171.8 | 0.85 |
| P5 | 40 | 163.2 | 0.94 |
| P6 | 40 | 162.1 | 1.05 |
| P7 | 40 | 160.4 | 1.05 |
| P8 | 40 | 161.0 | 1.10 |

**Acknowledgements**

The author would like to acknowledge the support of S. Balzer and M. Hoverson of the GRC team.

**Conclusion**

Eight pulse performance of the target has been demonstrated. Preliminary results indicate spot sizes are of radiographic quality. Further studies are required to improve the observed spot size as well as determine the dose limitations and flexibility of eight pulse radiography.

[1] M.E. Schulze et al., Commissioning the DARHT-II Accelerator Downstream Transport and Target, Proceedings of LINAC08, Victoria, BC, Canada, p 434.
[2] M.E. Schulze et al., Commissioning the DARHT-II Scaled Accelerator Downstream Transport, Proceedings of PAC07, Albuquerque, NM, USA, p 2627.