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FOUR X-RAY PULSES WITHIN 10 ns AT LCLS*

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Abstract

The X-Ray FEL at SLAC or LCLS delivers typically one bunch at the time. Different schemes of two bunches have been developed: Two bucket, twin bunch, split undulator, and fresh slice. Here we discuss a four bunch or even eight bunch setup, separated by 2 RF buckets or 0.7 ns. The demand comes from MEC (Matter in Extreme Conditions) experiments [1], where high-power laser beams with Joule-class energies create impulsive pressure waves compressing materials on time scales of the order of ns. Eight snapshots for a single experiment will allow measuring the compression history, structural phase transitions into new high-pressure material states, and have the potential to resolve the transition kinetics time scales.

TWO BUNCHES

Many photon experiments have been performed using two bunches with up to 210 ns separation for pump-probe and probe-probe setups [2]. There is still the problem for further separations due to differences in RF kicks which require small kickers to get the transverse overlap [3]. Here we discuss two additional two bunch observations.

K-Mono Heating Effect

It was observed that the second beam was moving around far down stream (270 m) on a screen (Fig. 1) after going through a K-Mono. The local heating on the first reflecting (and absorbing) surface deforms it enough so that the second bunch is deformed into a ring with about 5-8 sigma radius. This behaviour was observed at 23.8 ns separation and about 1.5 mJ per bunch. By reducing the photon intensity which is necessary anyway for probe-probe experiments, which require the K-Mono, the second bunch got stable too.

Bunch Separation Jitter

For the typical experiments with a few to many ns time separation it is not very relevant to how much this separation jitters. This changes when looking into an oscillator scheme [4] where the x-rays of the first bunch are sent back over many meters to seed the next bunch. In this scenario the jitter should be a fraction of the bunch length. Figure 2 (top) shows the two bunches which were 122.5 ns apart on the screen just before the dump. The measured bunch lengths were around 100 fs (FWHM). The left bunch is somewhat longer and the right bunch shows micro-bunch energy ripples (vertical) since only one laser heater was setup. The time separation jitter distribution of the two bunches is with 12 fs (rms) about a factor of 3.5 smaller than the rms bunch lengths (Fig. 2 bottom).

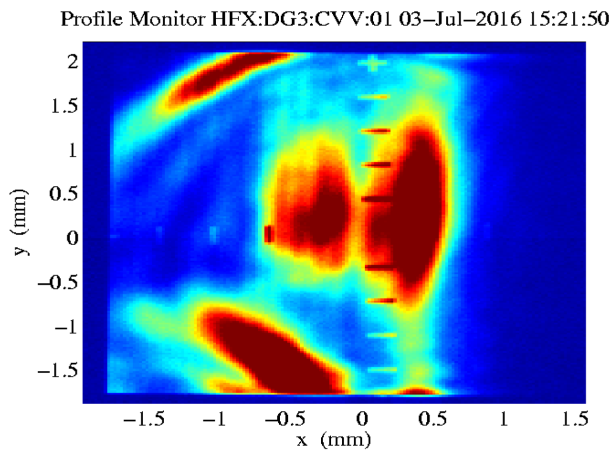

Figure 1: Profile monitor screen 270 m downstream of the K-Mono. The first bunch is where the two central lopes are (from the old, non-prefect mirrors). The second bunch is from pulse to pulse very different and here on a part of a circle which is already outside some collimation jaws.

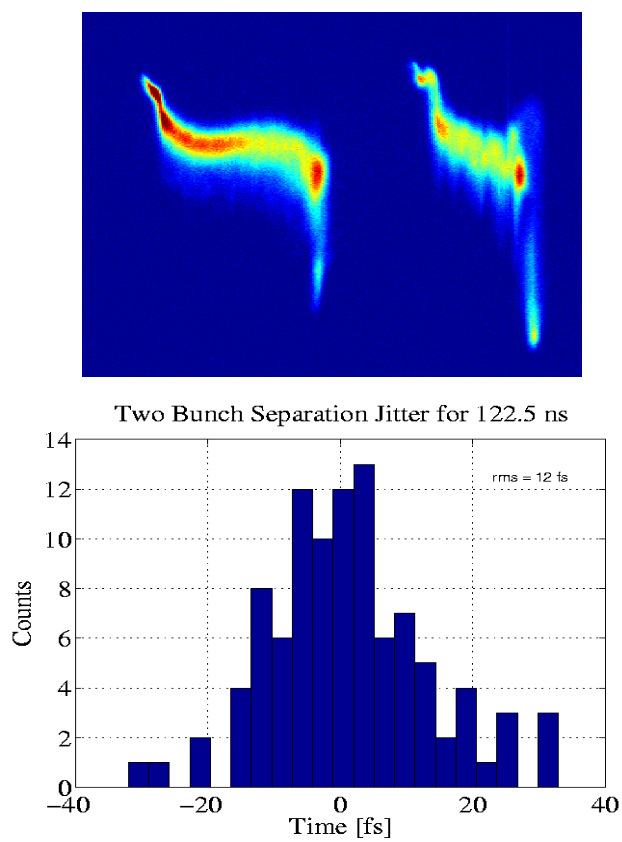

Figure 2: Two-bunch timing separation jitter measured by looking at the bunch separation on the dump screen (top) which is used together with the transverse deflection cavity XTCAV.

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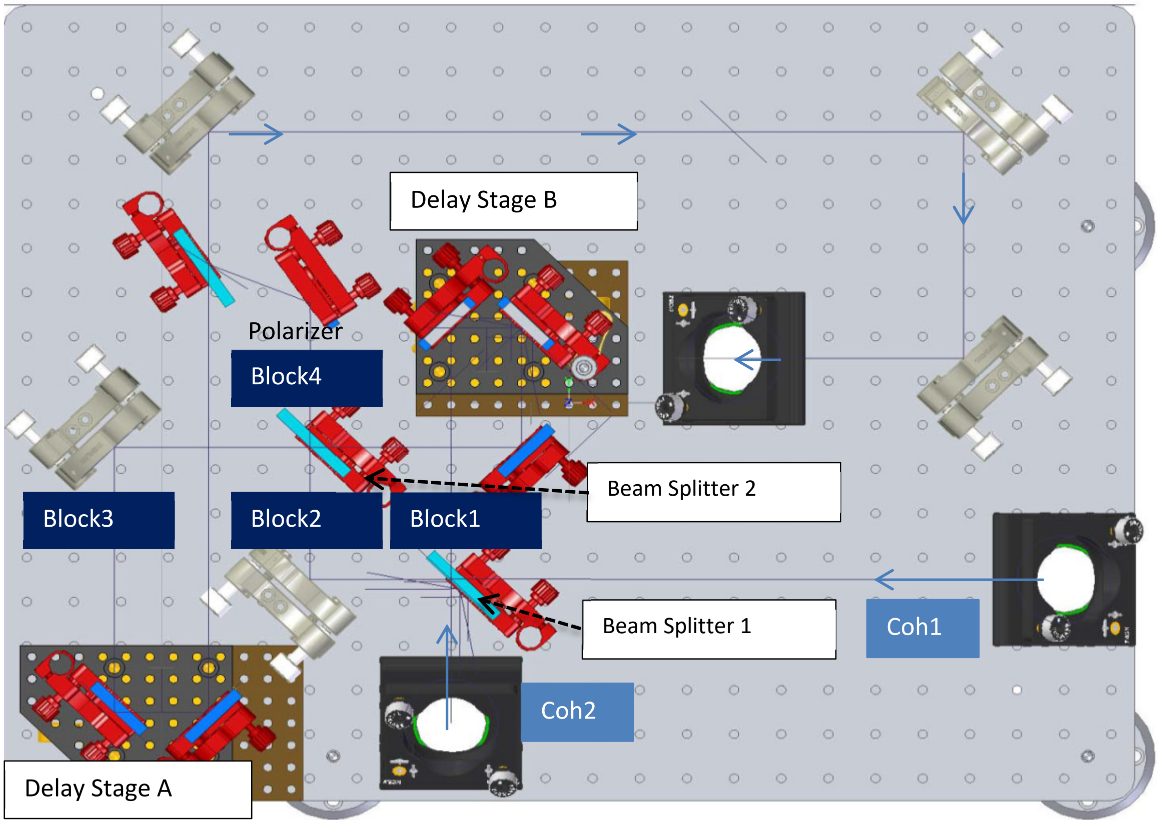

Figure 3: Multi Pulse Pulse-Stacker setup to create up to eight laser pulses for the injector gun. The two Coherent lasers (Coh1 and Coh2) enter the elevated 18x24 inch board from below. Beam splitter 1 creates two pulses of which one gets delayed by Delay Stage B (0.7 ns), they get combined and split again by beam splitter 2. The combined pulses 1 and 2 get rotated by a polarizer and go to the final combiner with a Brewster angle. The splitter pulses 3 and 4 get further delayed by Delay Stage A (1.4, 2.1 ns) before finally being combined again and send back down to the main laser table. Four combinations of two blocks pick out a single pulse. Inserting one block at a time creates four different combinations of two pulses, while replacing Beam Splitter 2 with a mirror or remove it gets two more two pulse combinations.

Table 1: Block Combinations and Power Measurement

Blocks in	Bunches	Enew [µJ]
None	1+2+3+4	153±2
1	1 + 3	76
2	2 + 4	80
3	1 + 2	77
4	3 + 4	79
1 + 3	1	40
2 + 3	2	38
1 + 4	3	39
2 + 4	4	42

FOUR BUNCHES

To get more bunches, four from one laser or even eight bunches with two lasers, the Multi Pulse Pulse-Stacker was setup (Fig. 3). Tab.1 shows the different combinations with blocks and bunch numbers and the balance intensities. It seems "strange" that two combinations are missing: Bunches 2 + 3 and 1 + 4. Looking at the setup it became obvious the second Beam Splitter (R = 50 / T = 50) has to be changed into a mirror (R = 100 / T = 0) for 2 + 3 and totally removed (T = 100 / R = 0) for the 1 + 4 bunch combination. This became necessary for an experiment which was asking for four bunches with longer separations to test a very fast camera [5]. We finally settled for 2.1 ns (Bunch 1 + 4) and two lasers with an additional gap between them of 3.85 ns. This matched the fast camera gates with 3 ns equidistant separation. Figure 4 shows the fast diode signals [6] of the four x-rays pulses at the experiment with an overlap of the camera gates. The corresponding longitudinal phase space images of the four bunches are visible in Fig. 5. It is obvious that the bunch lengths and the energies are different, but since it didn't matter for the camera tests it was not further optimized. Only the measured intensities were equalized and 3.5 mJ achieved for the sum. The differences in the beam spots were very stable even till the next day.

BEAM SETUP AND TUNING

To get to the above mentioned results many things had to be setup and tuned. We will discuss the major steps for the two laser setup and beam power issues.

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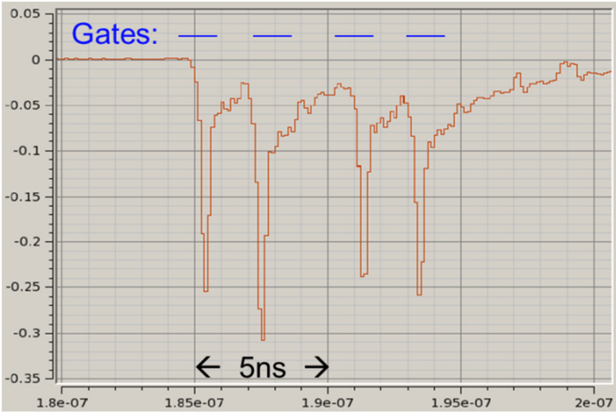

Figure 4: Fast diode signal (red) shows that the x-ray intensities of the four bunches are with 20 % the same. The equidistant camera gates (blue) will integrate the x-rays response late or early in the gate.

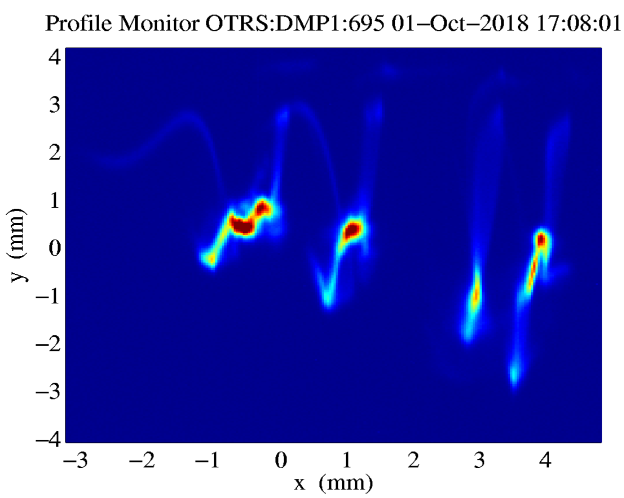

Figure 5: Four bunches on the dump screen. Vertical axis is energy, horizontal is time. From right to left is L2B1 (Laser 2 Bunch 1), L2B4, L1B1, L1B4. B4 has a short bunch length and is close to B1 for L2, while B4 is long and further behind for L1, although they go through the same delays.

Laser Setup and Tuning

Both lasers together were setup by hand for the first time producing electrons. The common timing had to be adjusted, -2 mm in BC1 (Bunch Compressor) required a ¾ turn clockwise on the delay stage. The transverse overlap indicated that one of the lasers had more clipping than the other, vertical adjustments on the laser table resulted in mainly horizontal electron motion. And finally a mirror between the delay stages was fine adjusted to get the two electron bunches overlapped at the other end in the undulator. For going to one bunch a block had to be inserted.

Beam Power Issues

Both lasers worked great after retracting the normal combiner. They produced four times 250 pC with about 30% head room. Getting all four bunches clipped in BC1 by the typical horn-cutting to 180 pC tripped the MPS (Machine Protection System), which we could have bypassed. We went for the reducing of the charge off the Gun down to 180 pC and did some retuning of the injector.

Finally after tuning the beams at 10 Hz and going up in rate to 120 Hz we tripped the ACM (Average Current Monitor) set at 80 nA, which cannot be bypassed. The maximum allowed charge of 80 nA/120 Hz = 667 pC was less than the assumed 1 nC, which we would have stayed under with 4*180 = 720 pC. Reducing the charge even further at the gun to about 150 pC, resulting in 600 pC for all four bunches was still tripping the ACM. Finally we decided to run the experiment at only 60 Hz. Looking at the BPM (Beam Position Monitor) sum signal (Fig. 6) which adds them like vectors where the angle depends on the separation, shows that the 350 pC of a typical 140 MHz BPM indicated 350/2.06*4 = 680 pC, still over the trip threshold.

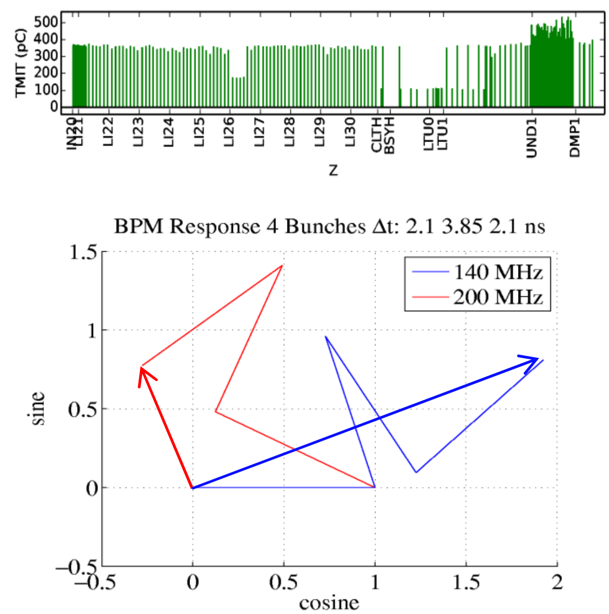

Figure 6: Vector addition of four BPM signals for different frequencies. The typical Linac BPM with 140 MHz (blue) shows about a factor of two (2.06) of the single bunch charge for the sum of four bunches, while an LTU (Linac To Undulator) BPM (red) shows with 73 % less than a single bunch. Four different types of BPMs are used along the accelerator (top).

CONCLUSION

Four bunches within 10 ns achieving nearly 1 mJ each were delivered to an experiment testing a fast x-ray camera response. Some laser room adjustments should be remoted, like block insertion, steering and delay in that order. The quite different longitudinal phase space for Bunch 4 of Laser 1 versus Bunch 4 of Laser 2 is still under investigation.

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