SAND2007-4073C

The Dynamics of Radiation Driven Gap Closure Across MegaGauss Fields on Z

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL8500.

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Acknowledgements

- John McGurn for interacting with Victor Konsarev to field his capillary EUV spectrometer.
- Tyler Weeks, our student intern from BYU, who returned to Sandia to field Sasha Shvelko’s EUV spectrometer.
- Bruce McWatters and Jason Podsednik for supporting the laser/framing camera system.
- Alan Carlson for persevering against all odds to successfully field the VUV fiber spectrometer.

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The main purpose of this shot series was two fold:

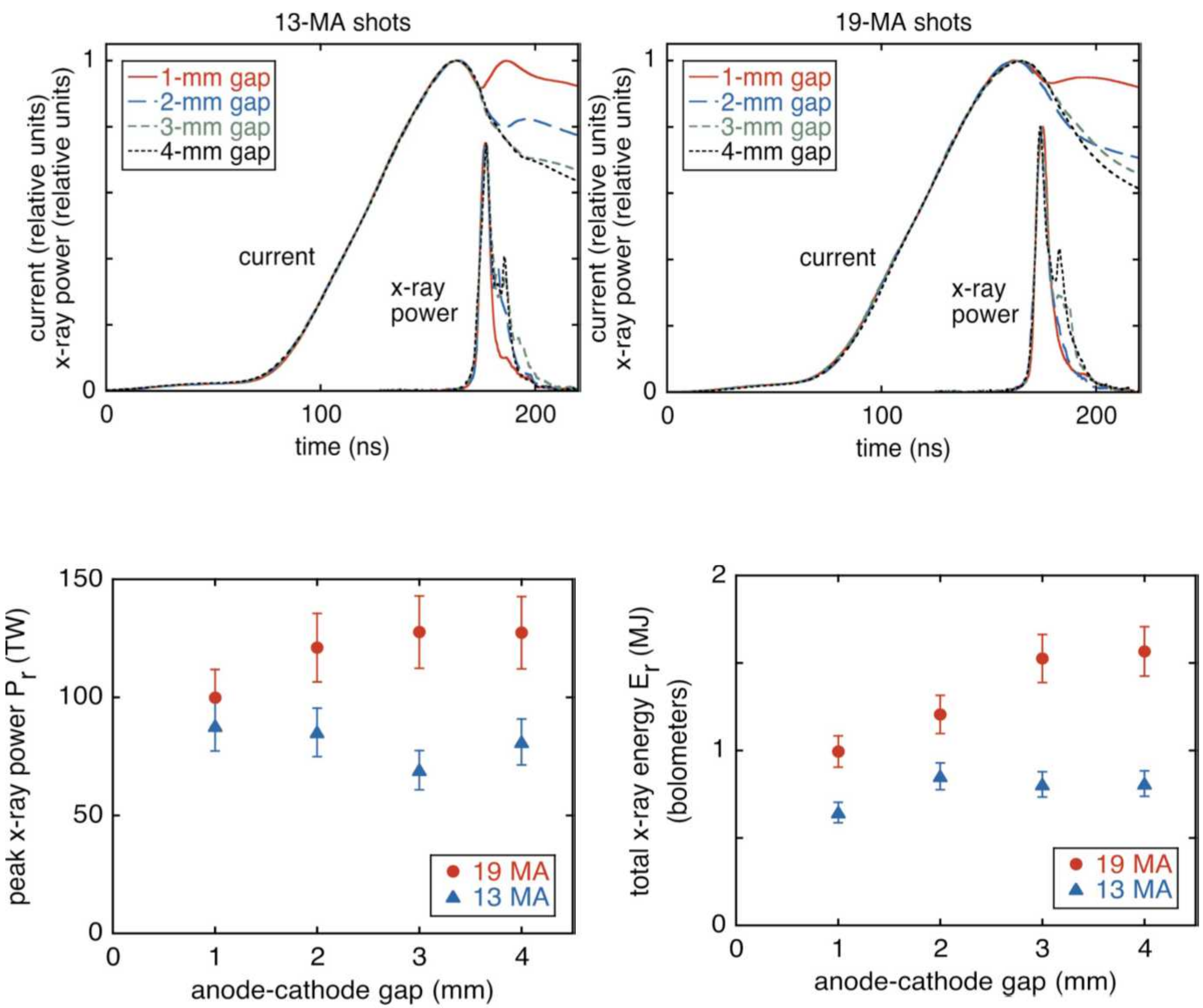
1. Observe closure of the power feed gap utilizing laser shadowgraphy, the ZBL monochromatic backlighter and various spectrometers.
2. Observe the redistribution of wire mass along the Z-axis as the array implodes. (Brent Jones used 1mm wide NaCl and Al dopant bands.)

Why is Gap Closure Important?

1. In a Z-pinch driven hohlraum, the power feed gap is an open area for radiation loss.
2. Therefore, the gap should be made as small as possible.
3. The lower limit is determined by gap closure shunting current from the pinch, decreasing peak power.

Background on gap closure dynamics.

W.A. Stygar, et. al, Phys. Rev. E **69**, 046403 (2004)



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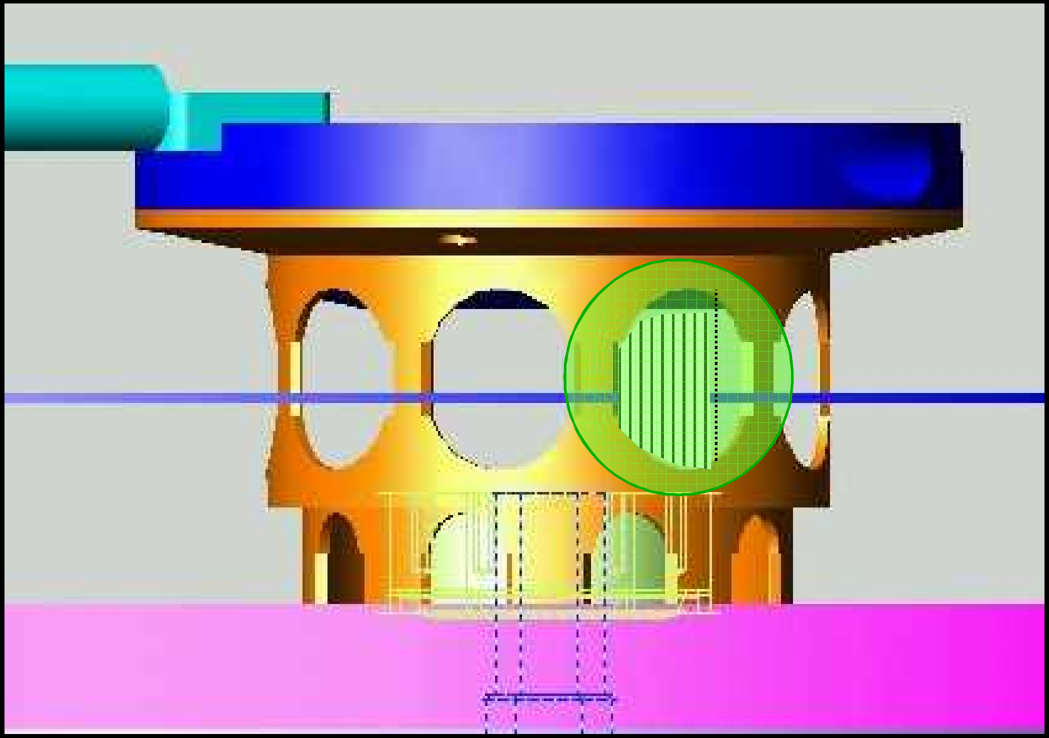
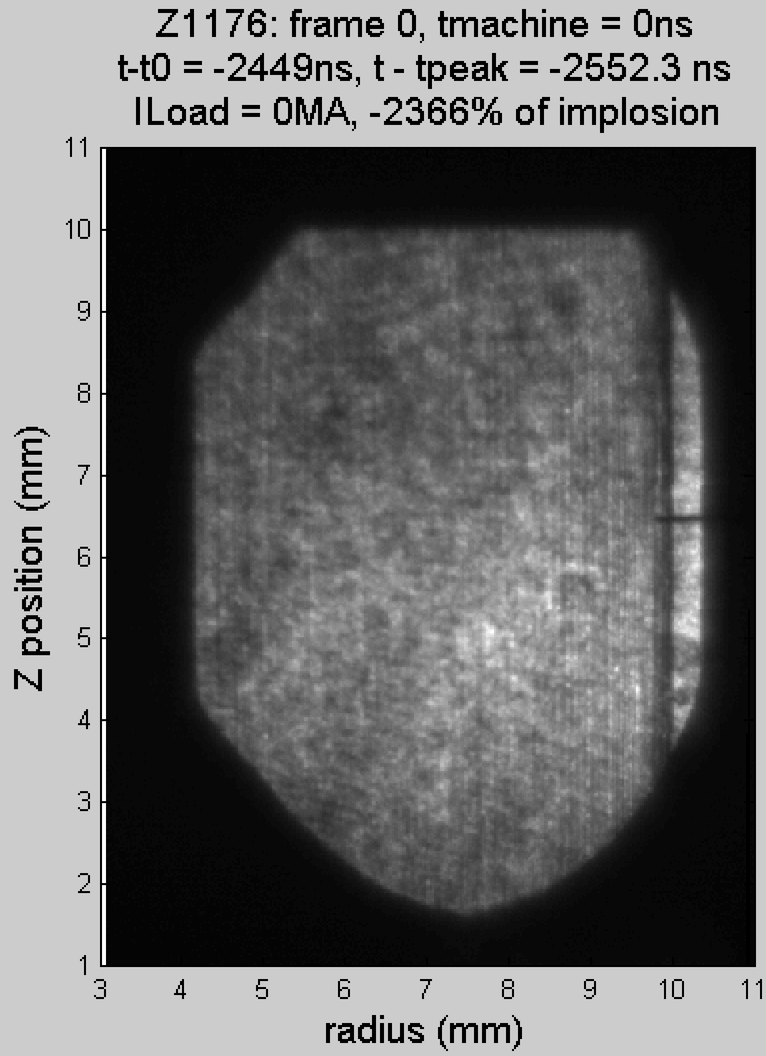
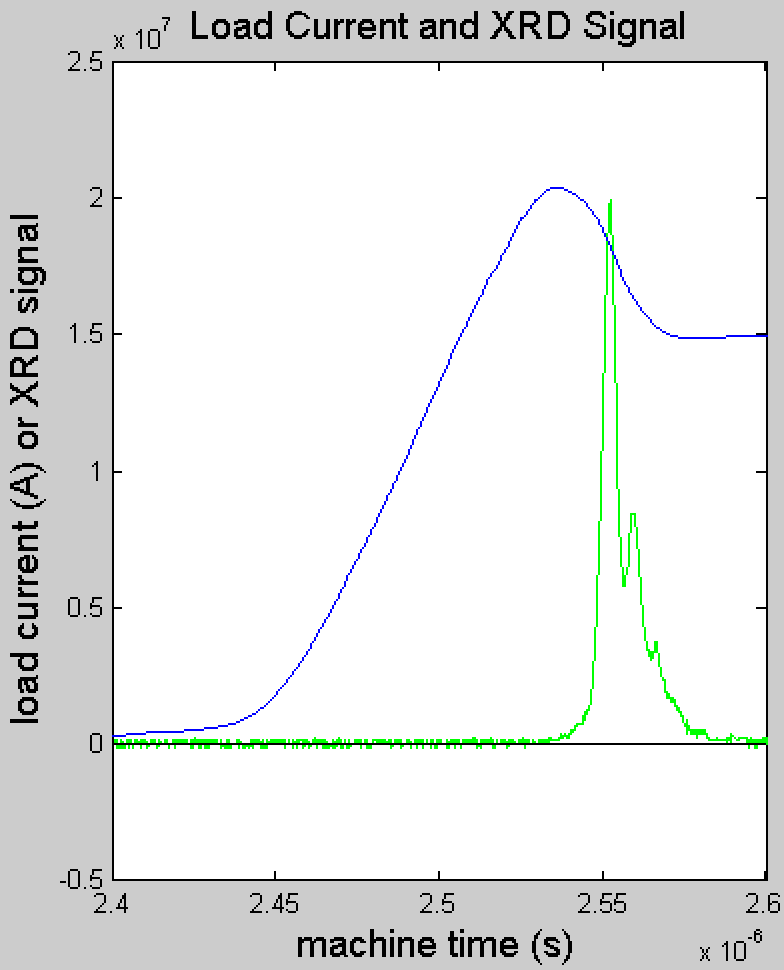
The Gap Closure Dynamics Shot Series was based on ½ of the doubled-ended Hohlraum ICF load.

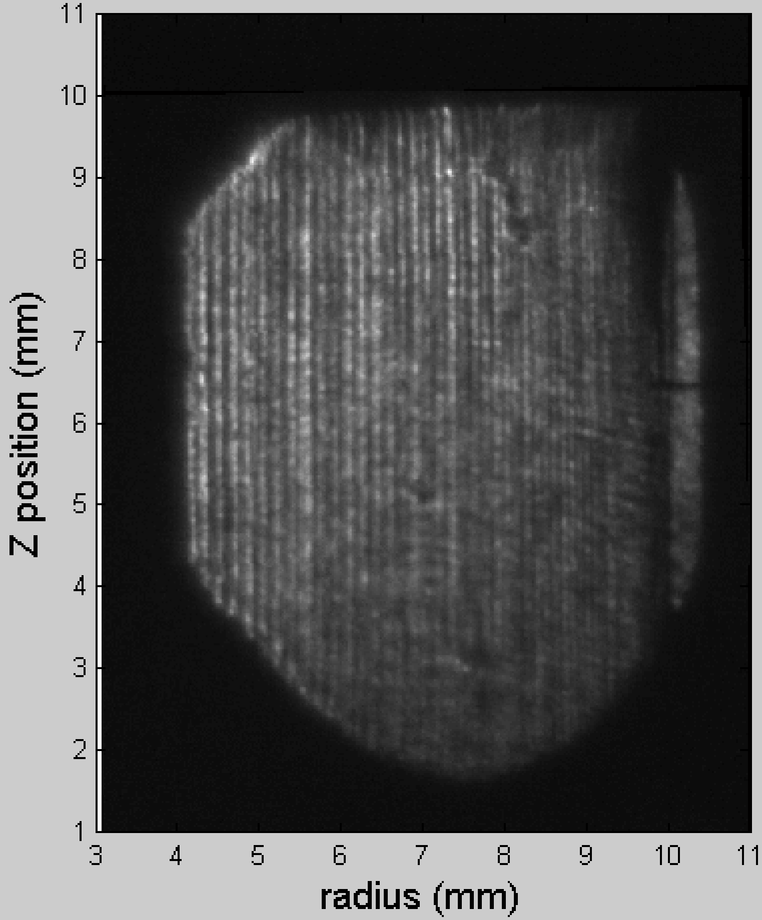
Z1176
Material: W
Array Diameter:
20 mm, 300 wires
Array Height: 10 mm
Wire Φ: 11.5 um
Array Mass: 6 mg



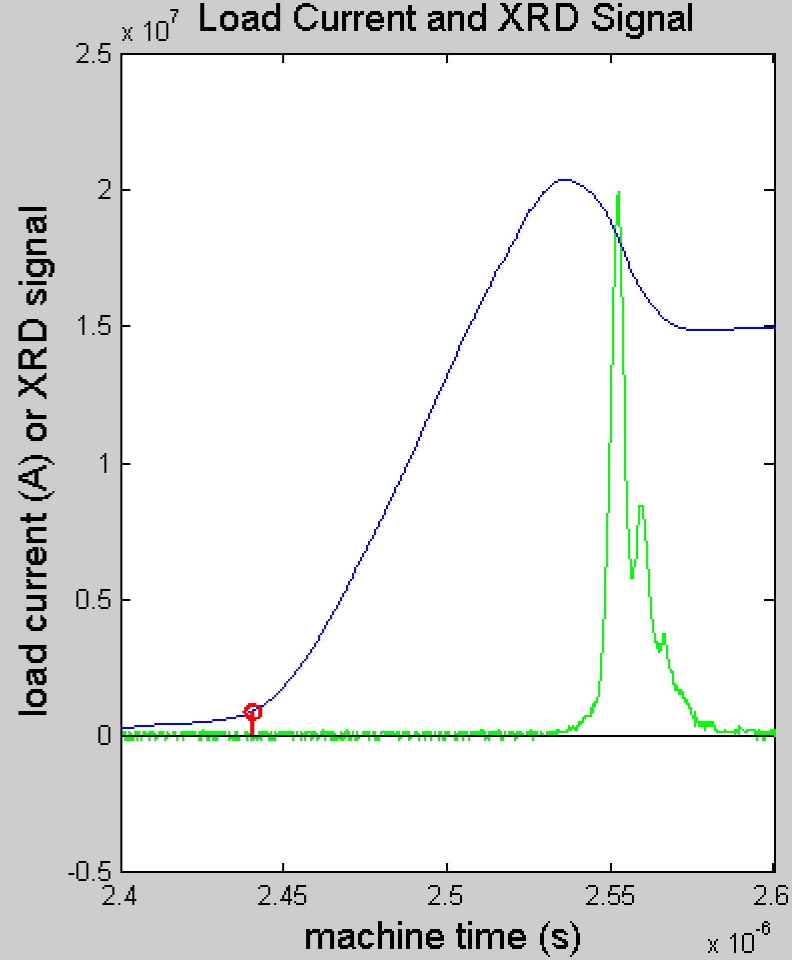

Z1176: frame 0, tmachine = 0ns
t-t0 = -2449ns, t - tpeak = -2552.3 ns
ILoad = 0MA, -2366% of implosion
Z position (mm)
radius (mm)
11
10
9
8
7
6
5
4
3
2
1
3
4
5
6
7
8
9
10
11

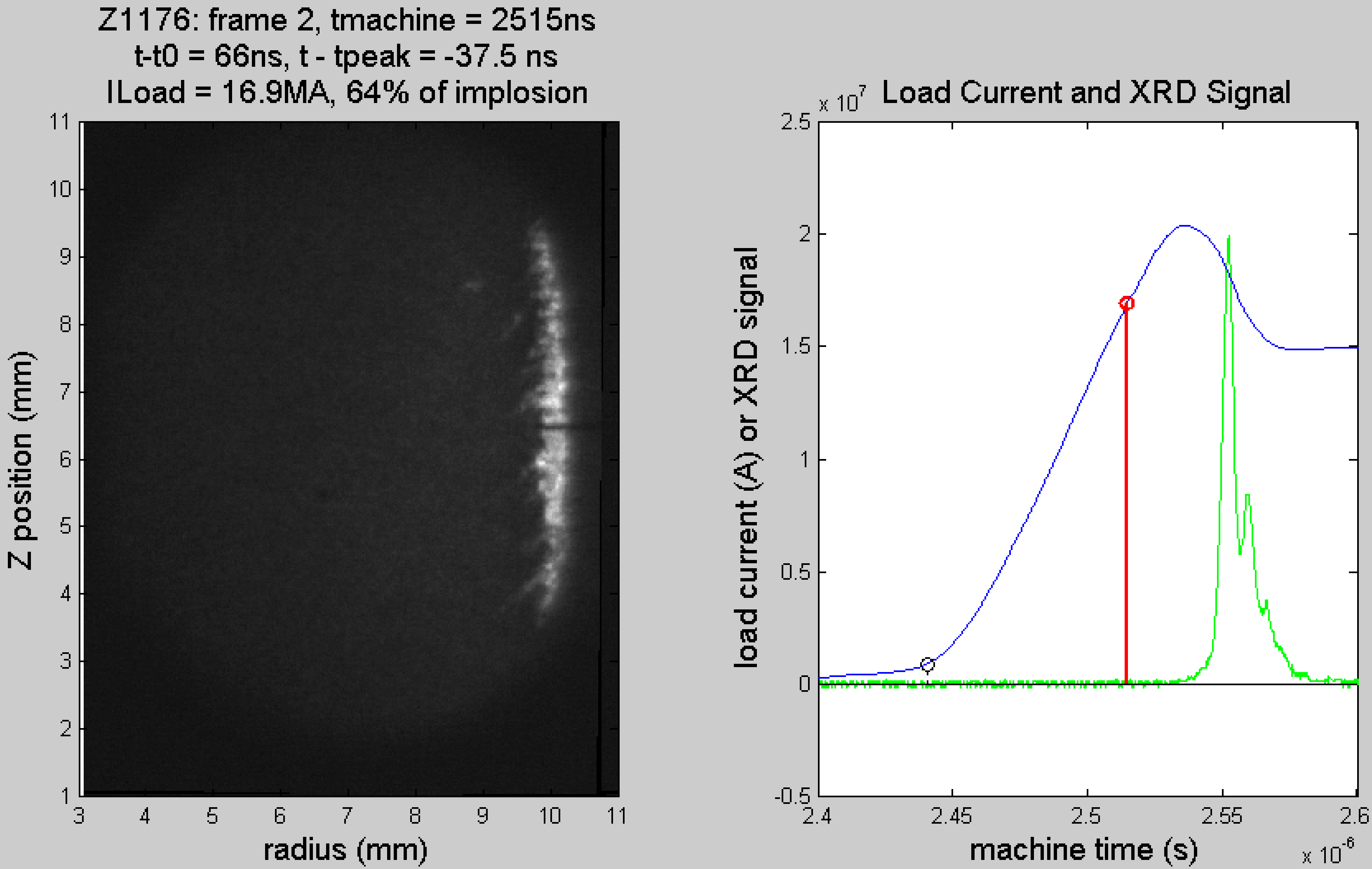

Load Current and XRD Signal
x 10^7
load current (A) or XRD signal
machine time (s)
x 10^-6
2.5
2
1.5
1
0.5
0
-0.5
2.4
2.45
2.5
2.55
2.6

Z1176: frame 1, tmachine = 2441ns
t-t0 = -8ns, t - tpeak = -111.6 ns
ILoad = 0.9MA, -8% of implosion

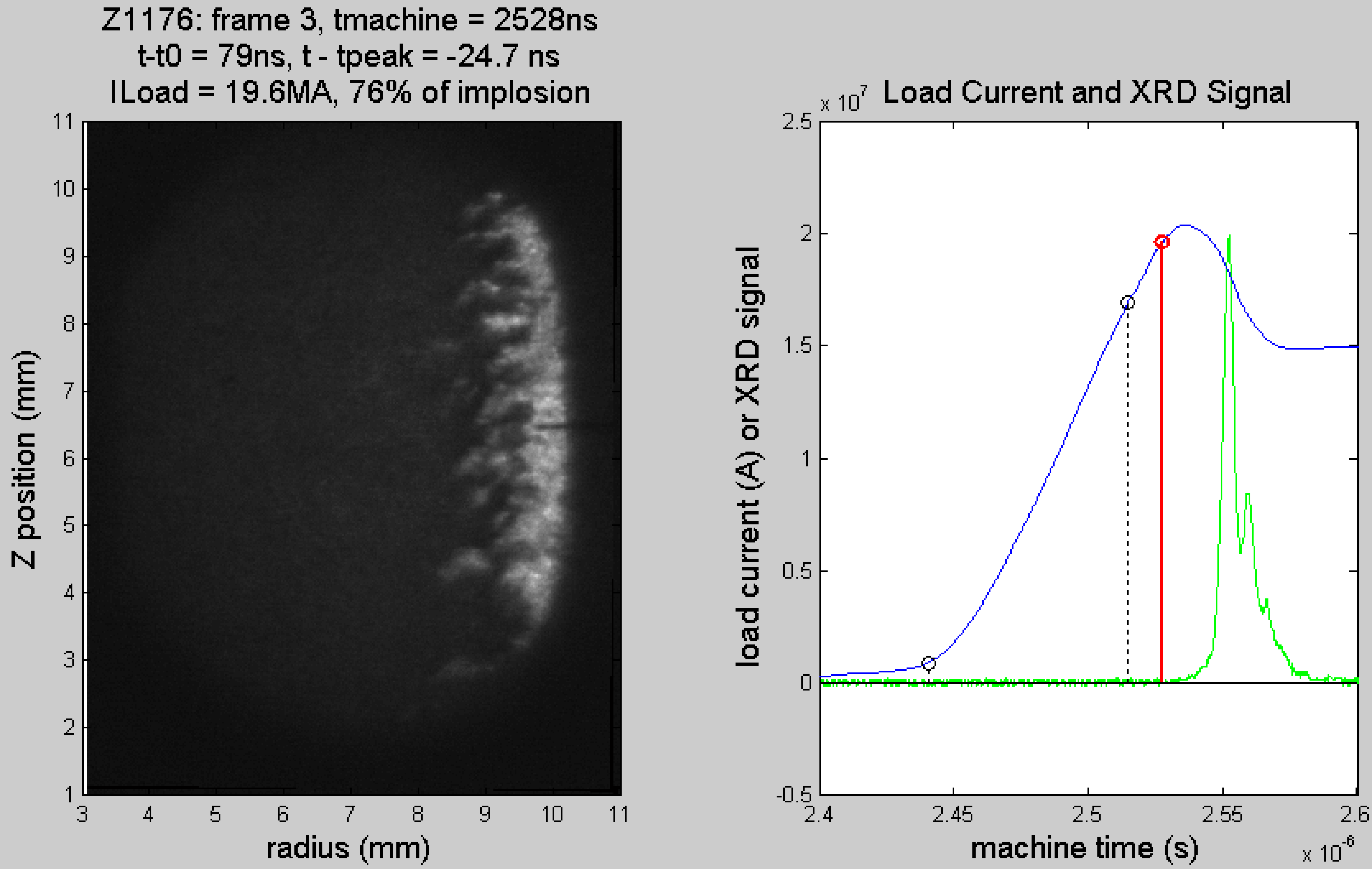


Load Current and XRD Signal

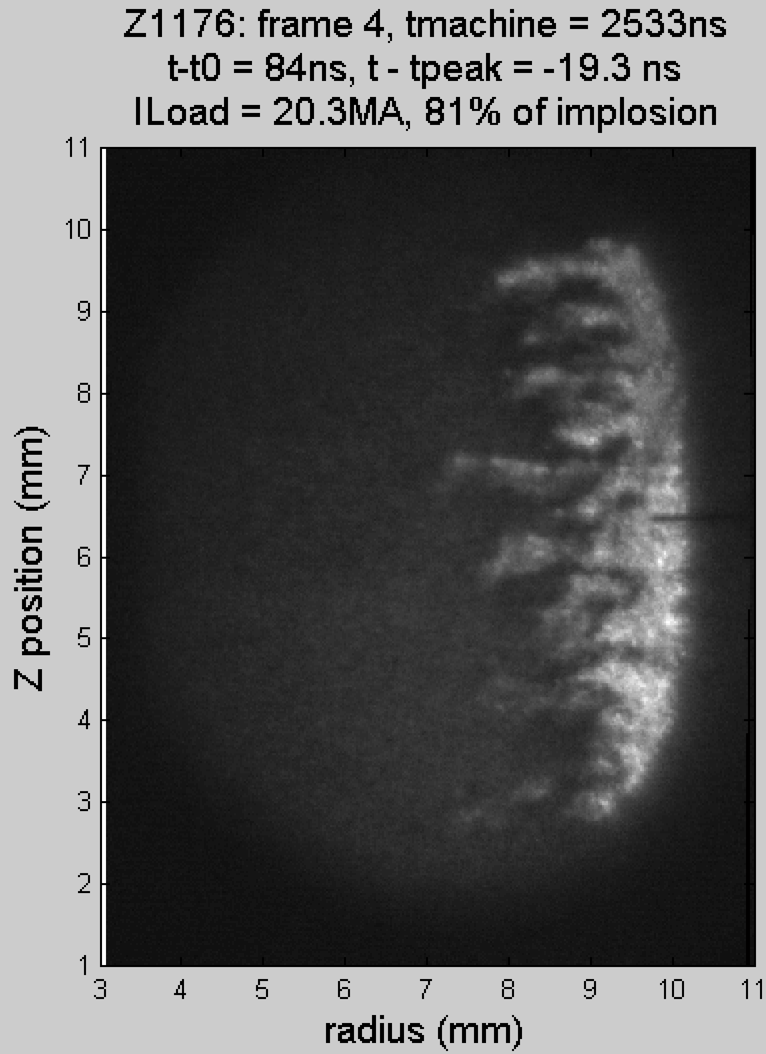




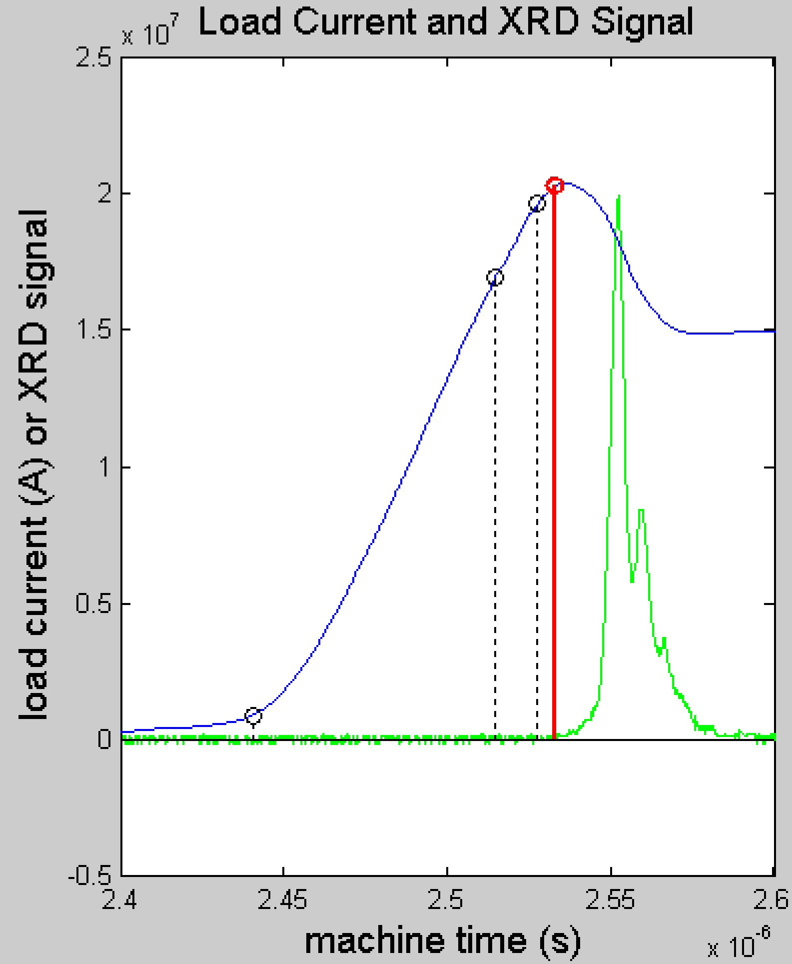
Z1176: frame 2, tmachine = 2515ns
t-t0 = 66ns, t - tpeak = -37.5 ns
ILoad = 16.9MA, 64% of implosion
Z position (mm)
radius (mm)
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal
machine time (s)
x 10^-6



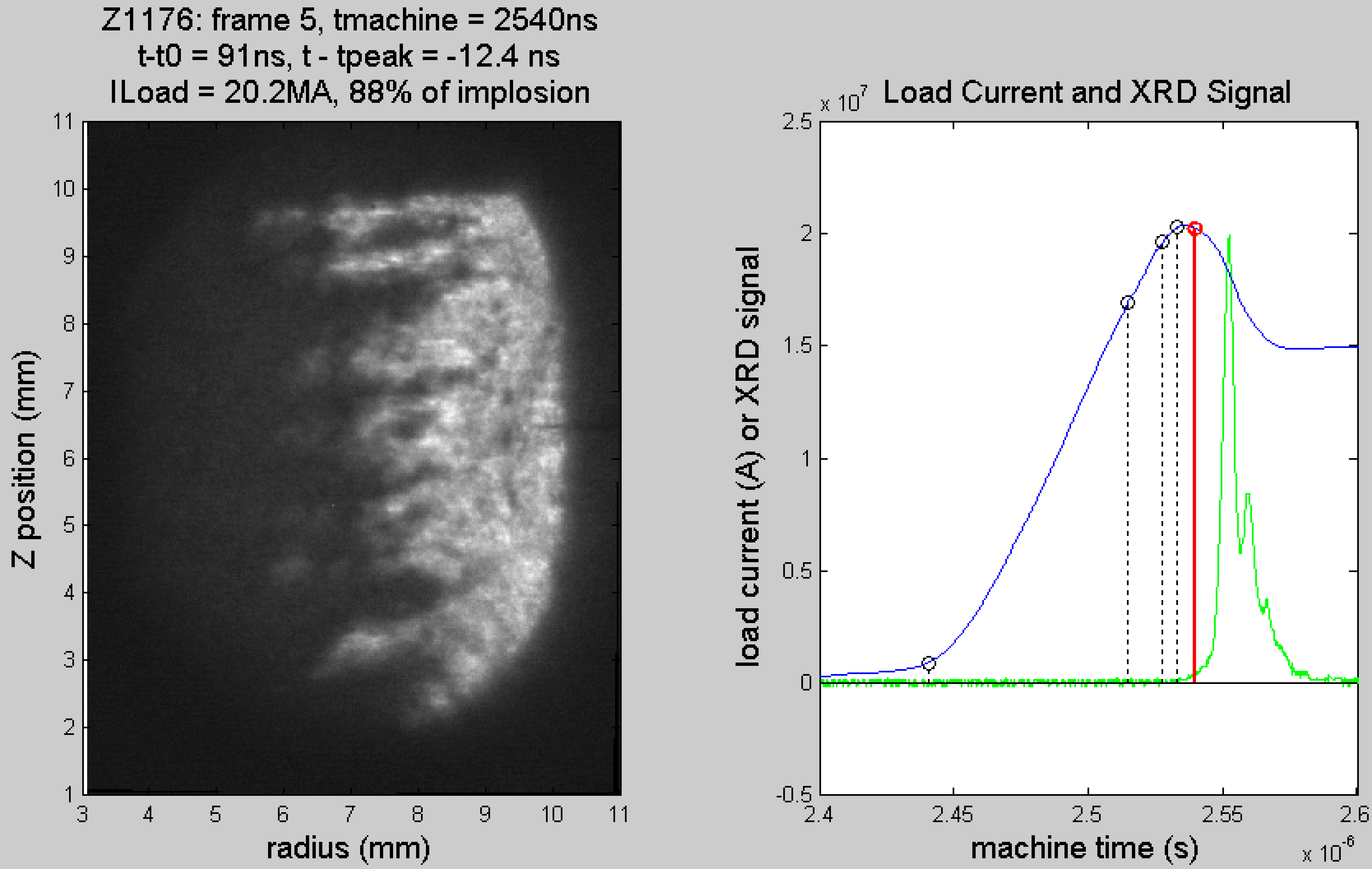
Z1176: frame 3, tmachine = 2528ns
t-t0 = 79ns, t - tpeak = -24.7 ns
ILoad = 19.6MA, 76% of implosion
Z position (mm)
radius (mm)
x 10^7
Load Current and XRD Signal
load current (A) or XRD signal
machine time (s)
x 10^-6



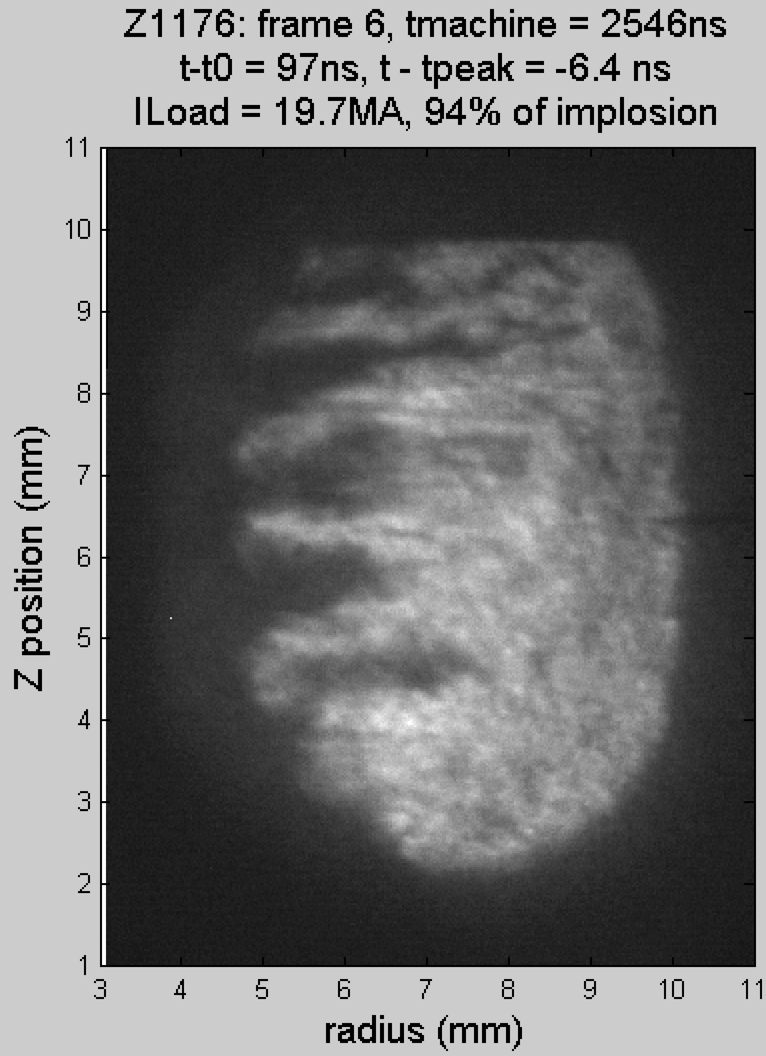
Z1176: frame 4, tmachine = 2533ns
t-t0 = 84ns, t - tpeak = -19.3 ns
ILoad = 20.3MA, 81% of implosion
Z position (mm)
radius (mm)



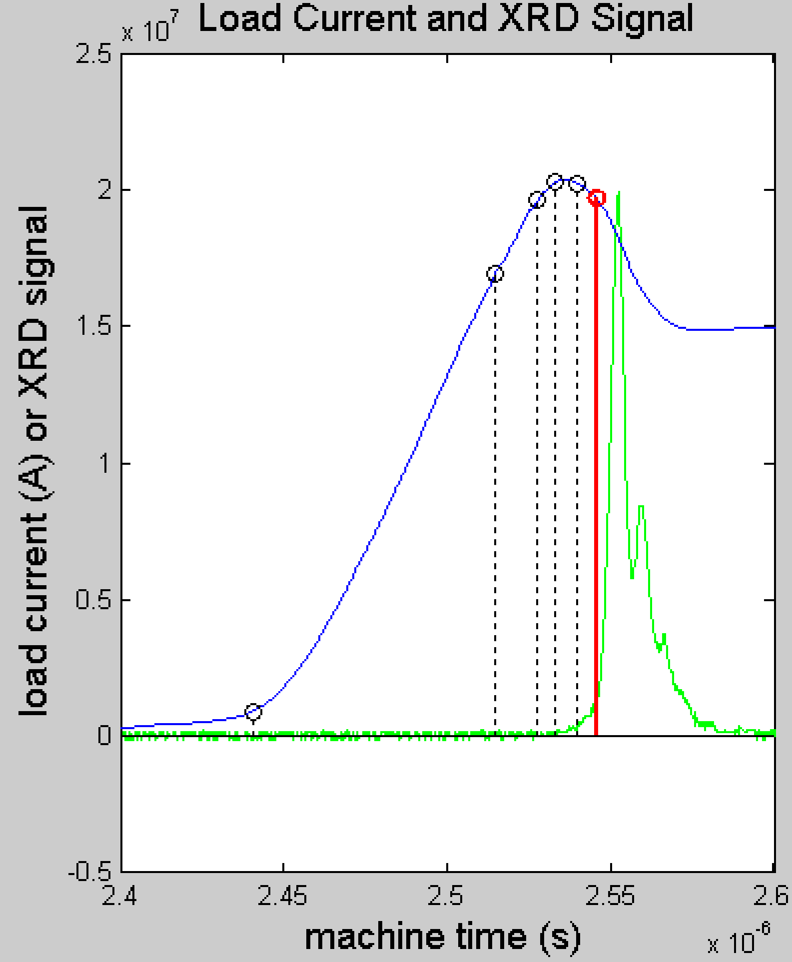
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal
machine time (s)
x 10^-6



Z1176: frame 5, tmachine = 2540ns
t-t0 = 91ns, t - tpeak = -12.4 ns
ILoad = 20.2MA, 88% of implosion
Z position (mm)
radius (mm)
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal
machine time (s)
x 10^-6

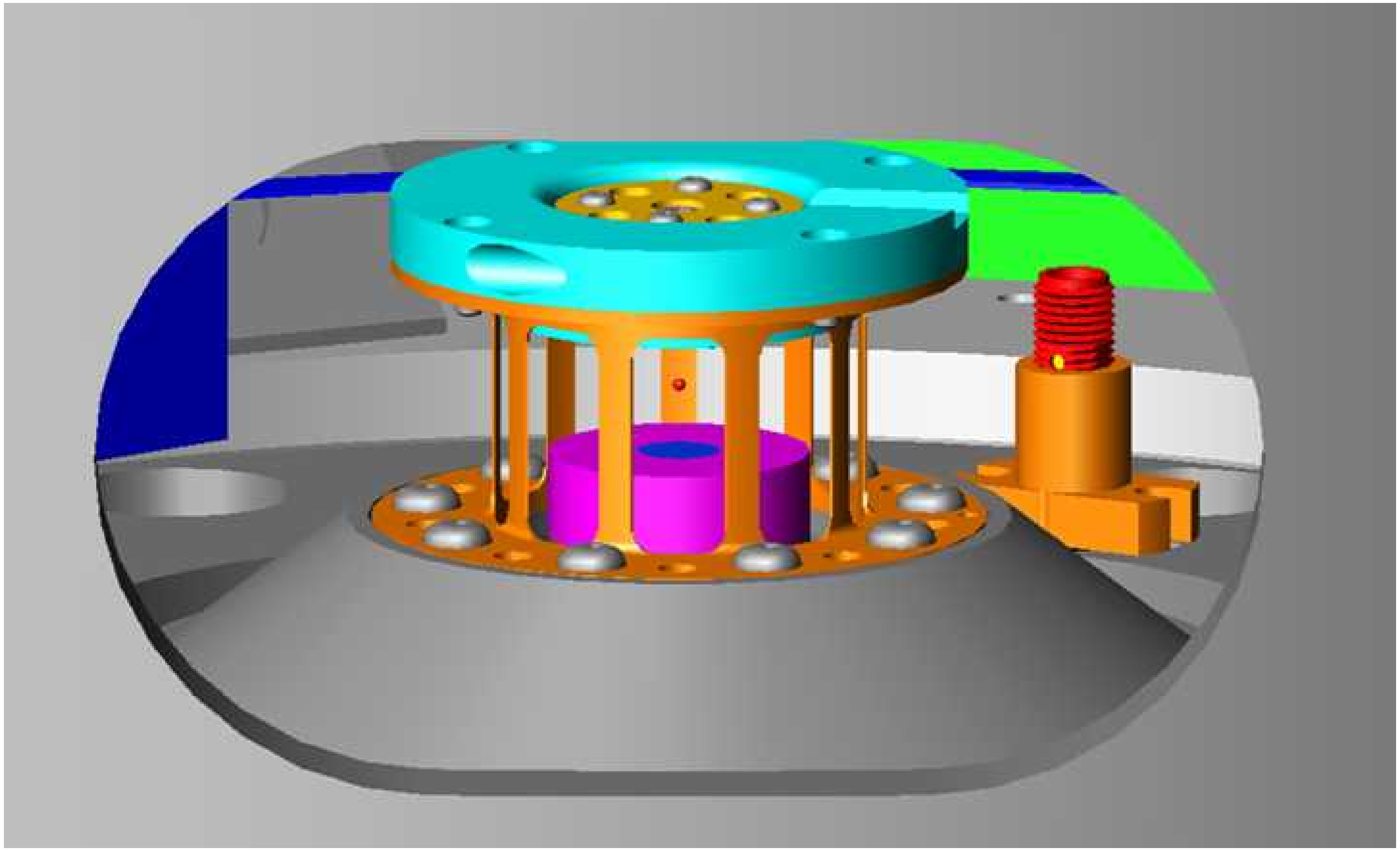


Z1176: frame 6, tmachine = 2546ns
t-t0 = 97ns, t - tpeak = -6.4 ns
ILoad = 19.7MA, 94% of implosion
Z position (mm)
radius (mm)

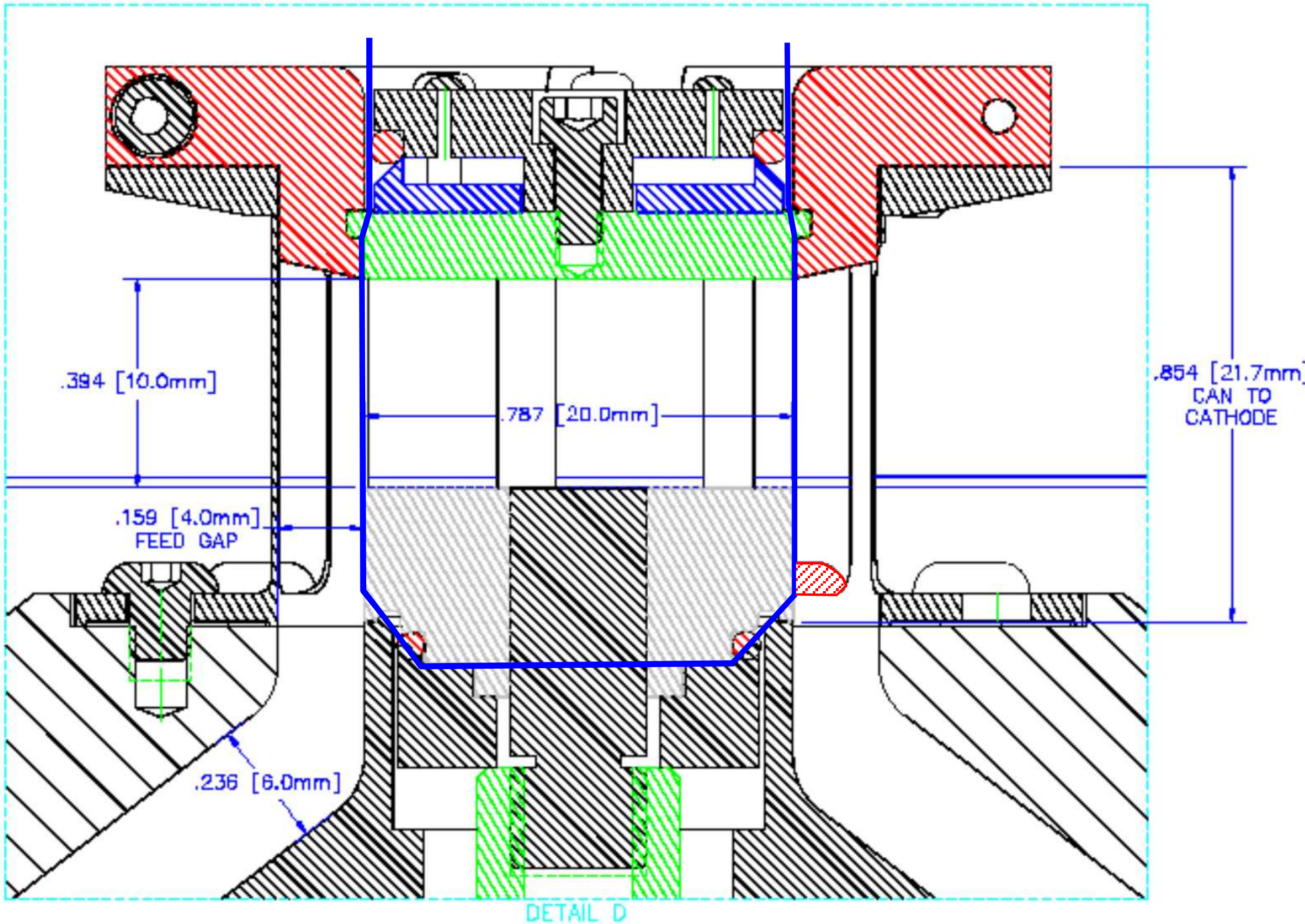


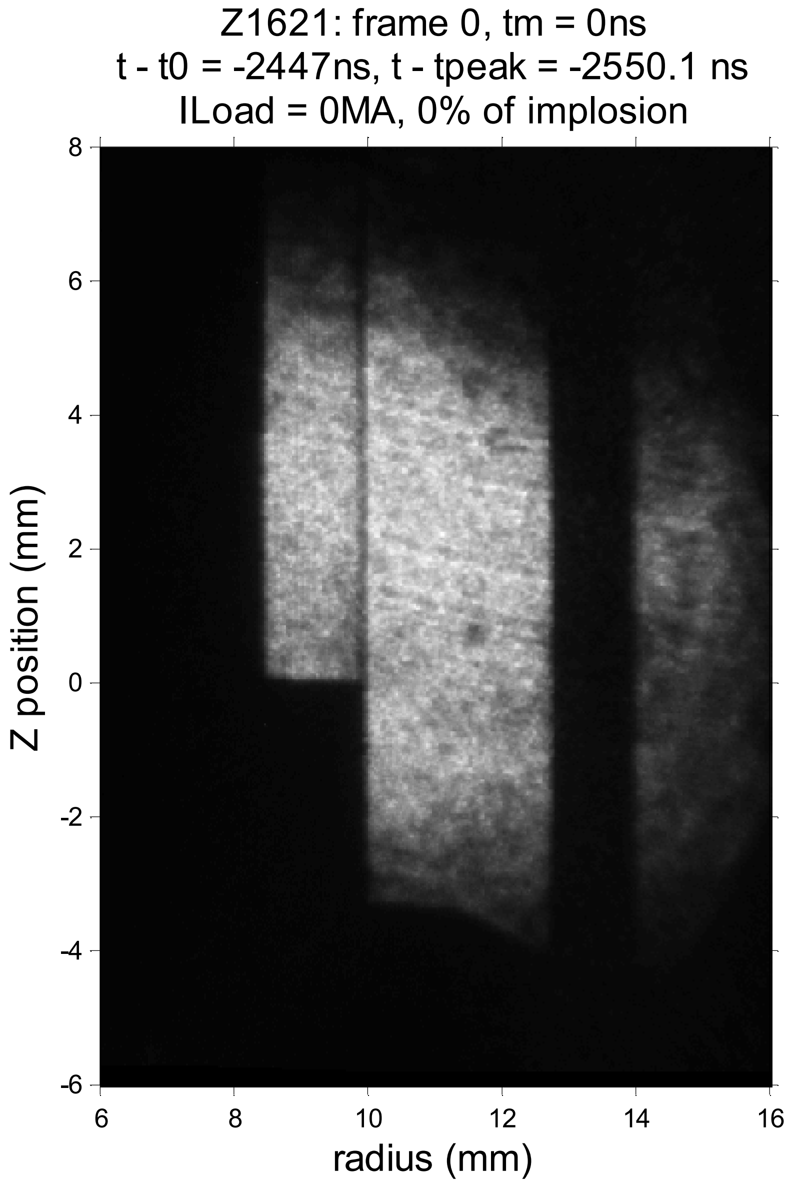
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal
machine time (s)
x 10^-6

CAD visualization of the load hardware looking down a 12° LOS shows the open can geometry, raised cathode stalk, and conical power feed modifications to support observation of the AK gap.

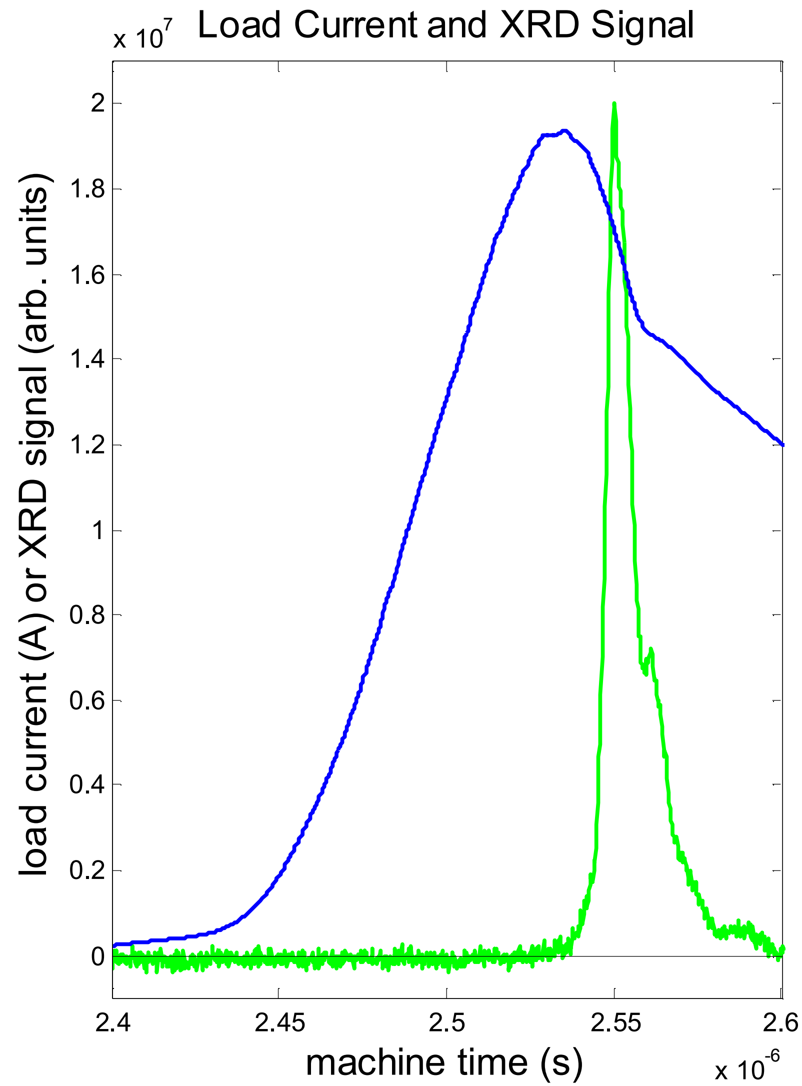


Drawing of the weightless wire array hardware shows the laser shadowgraph view with dimensions.

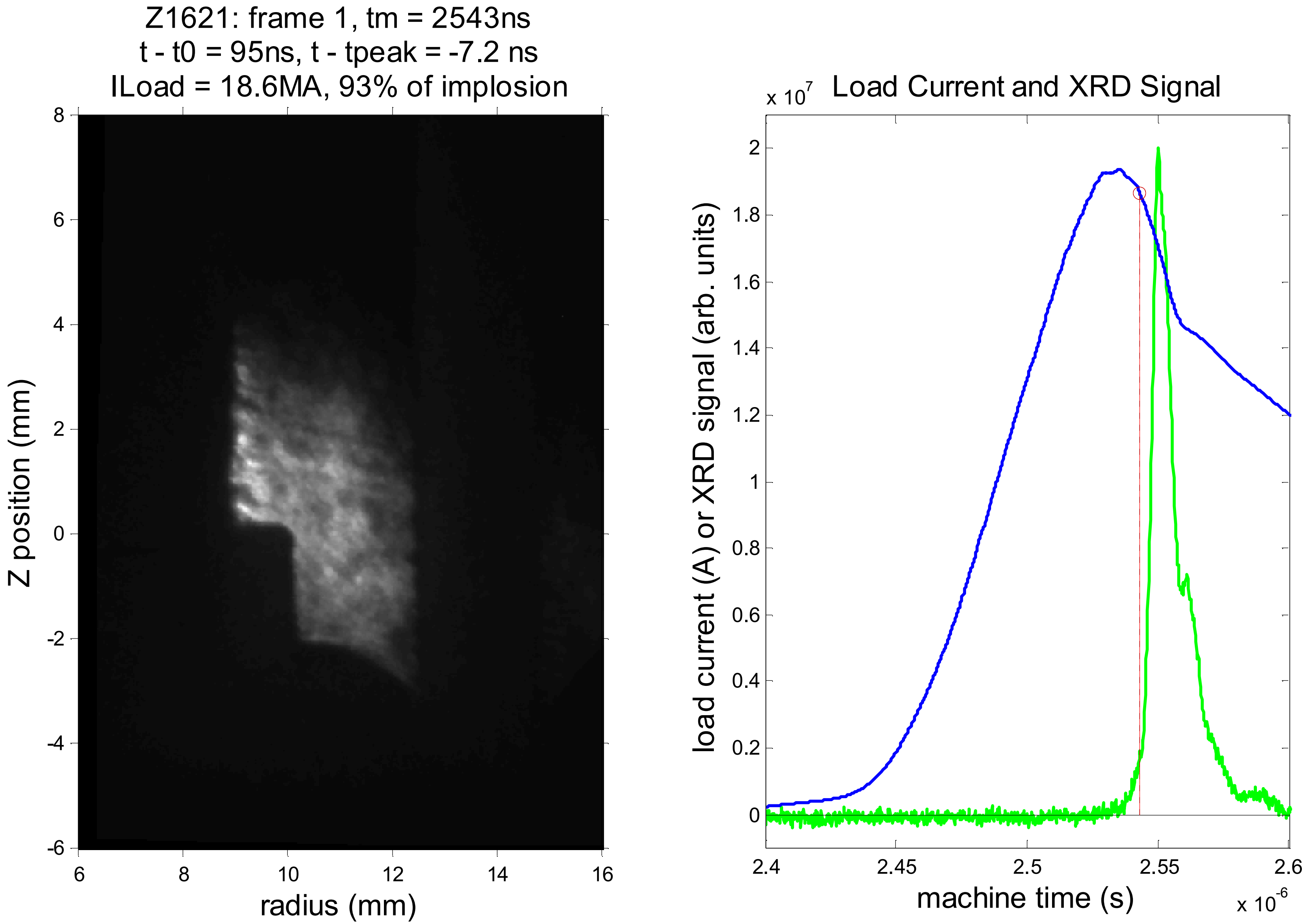


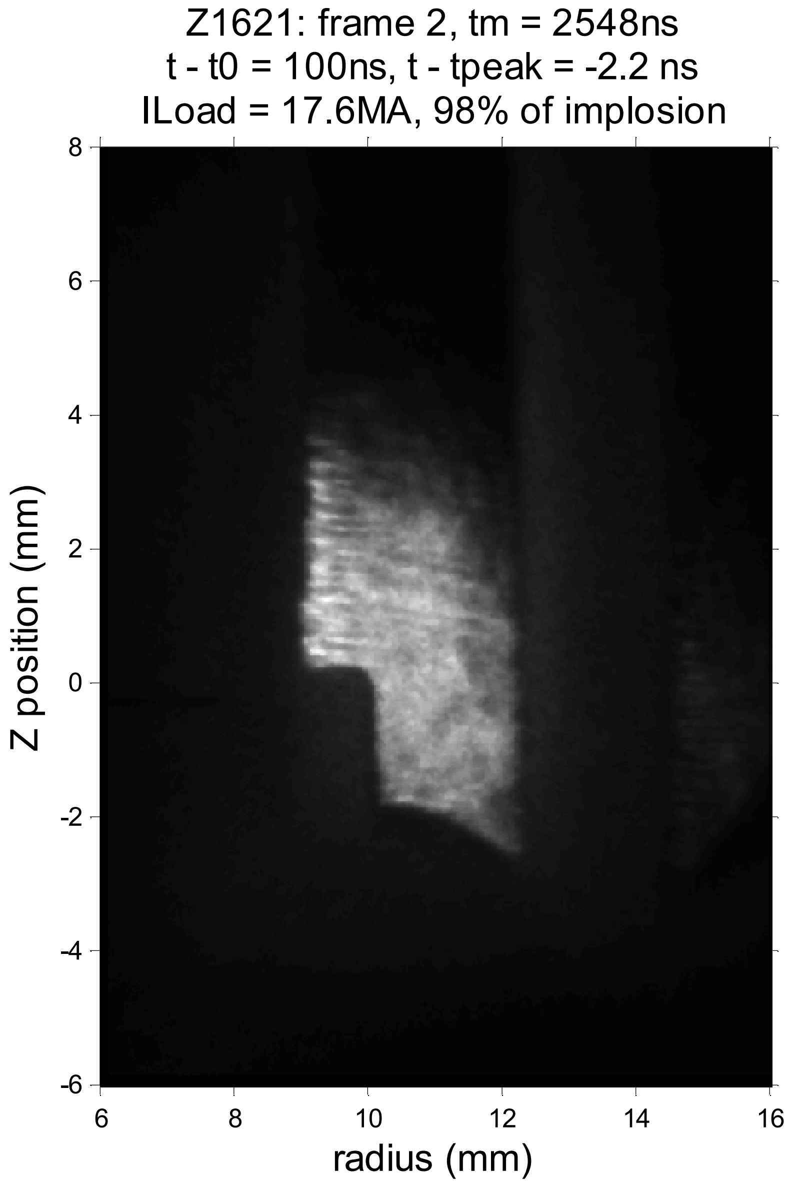


Z1621: frame 0, tm = 0ns
t - t0 = -2447ns, t - tpeak = -2550.1 ns
ILoad = 0MA, 0% of implosion
Z position (mm)
radius (mm)

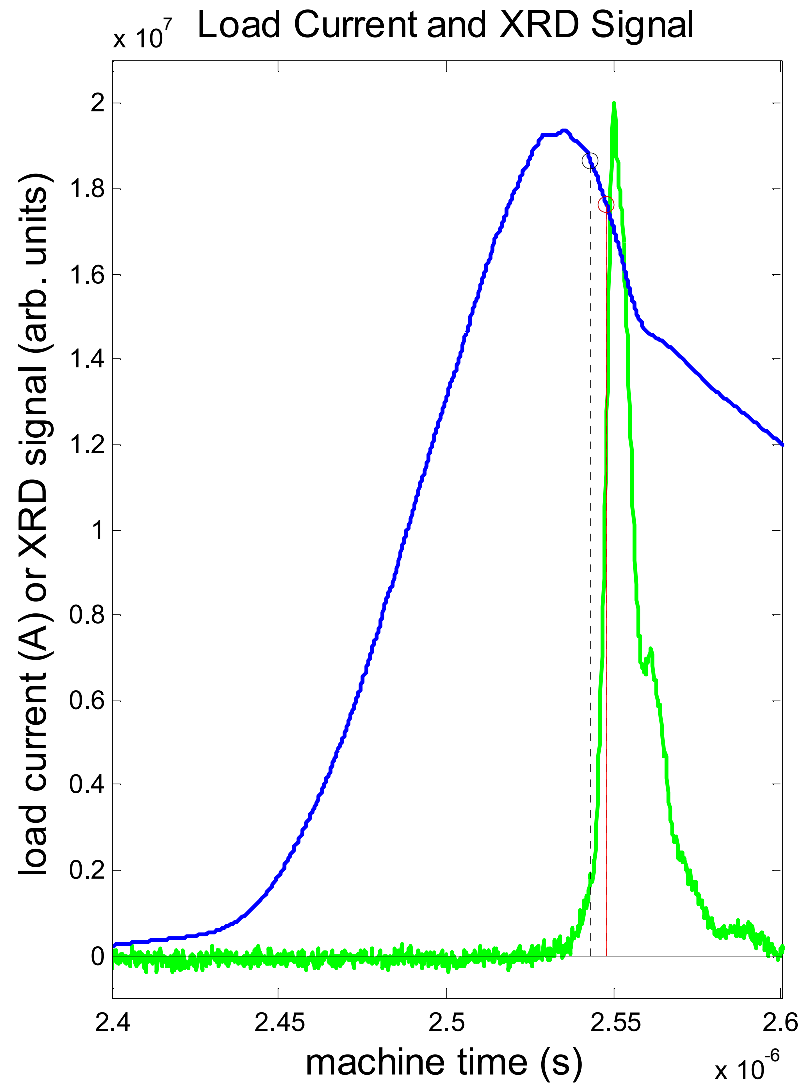


Load Current and XRD Signal
x 10^7
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6

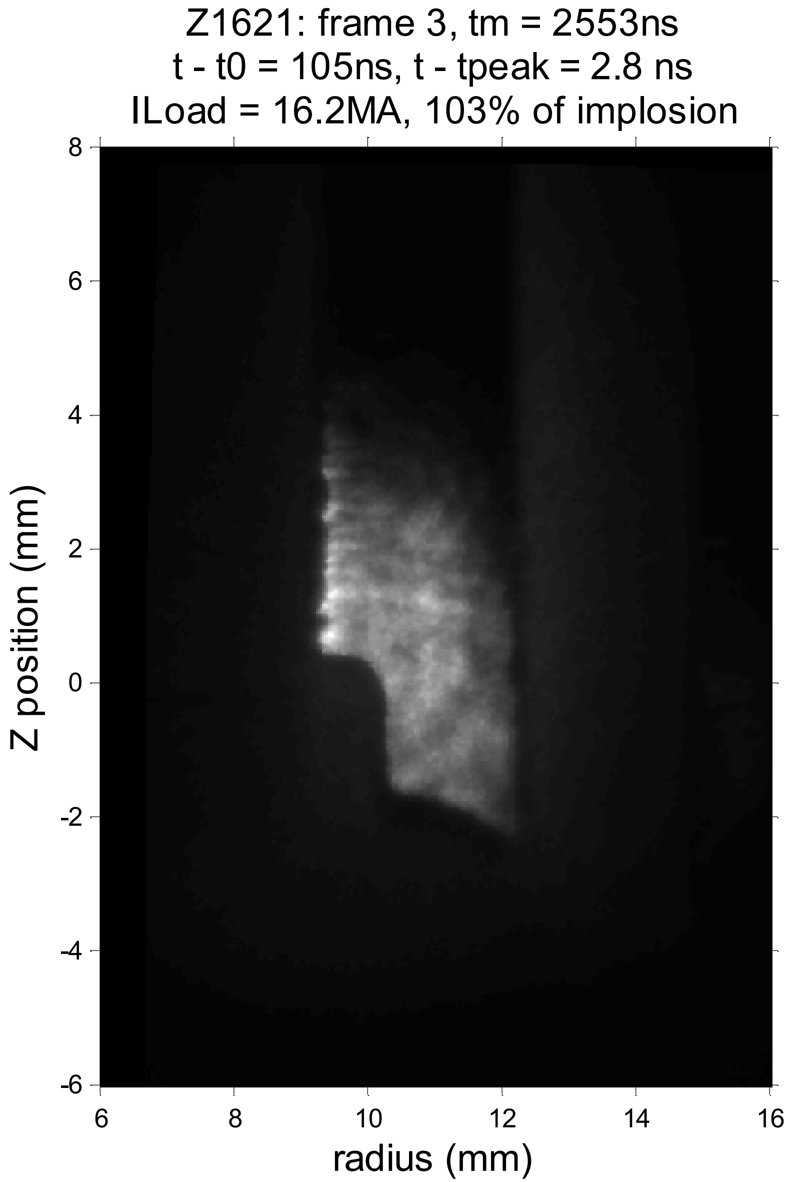

Z1621: frame 1, tm = 2543ns
t - t0 = 95ns, t - tpeak = -7.2 ns
ILoad = 18.6MA, 93% of implosion
Z position (mm)
radius (mm)
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6



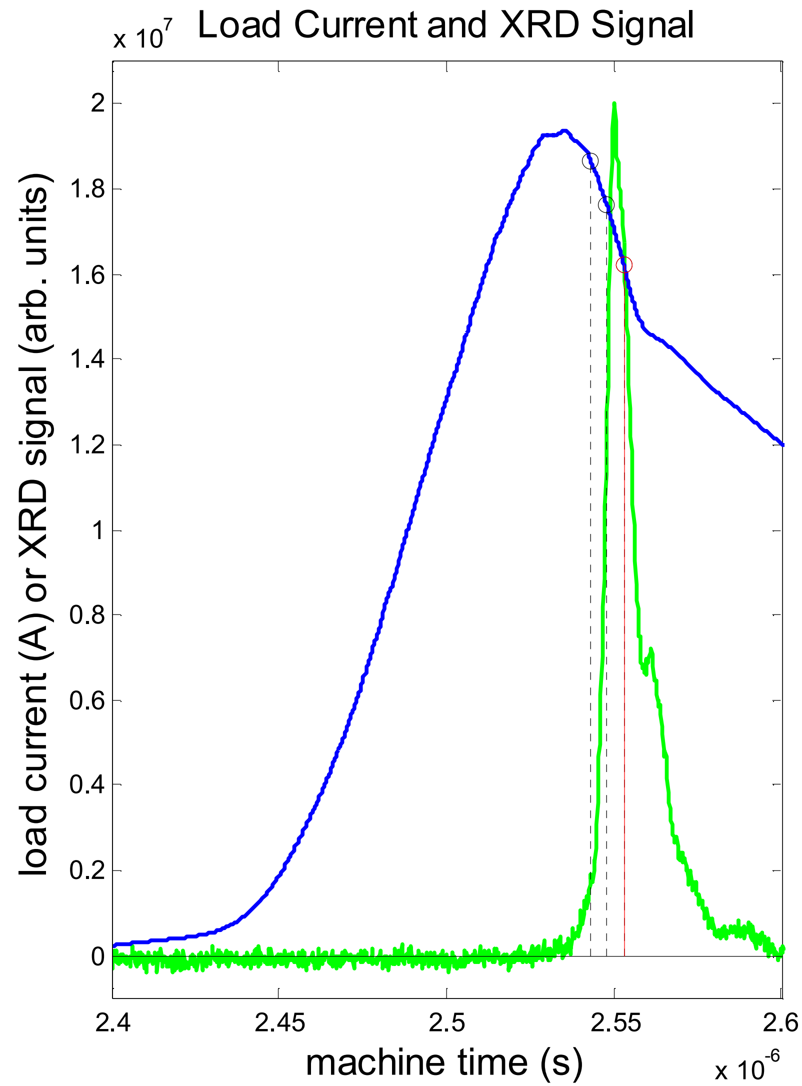
Z1621: frame 2, tm = 2548ns
t - t0 = 100ns, t - tpeak = -2.2 ns
ILoad = 17.6MA, 98% of implosion
Z position (mm)
radius (mm)



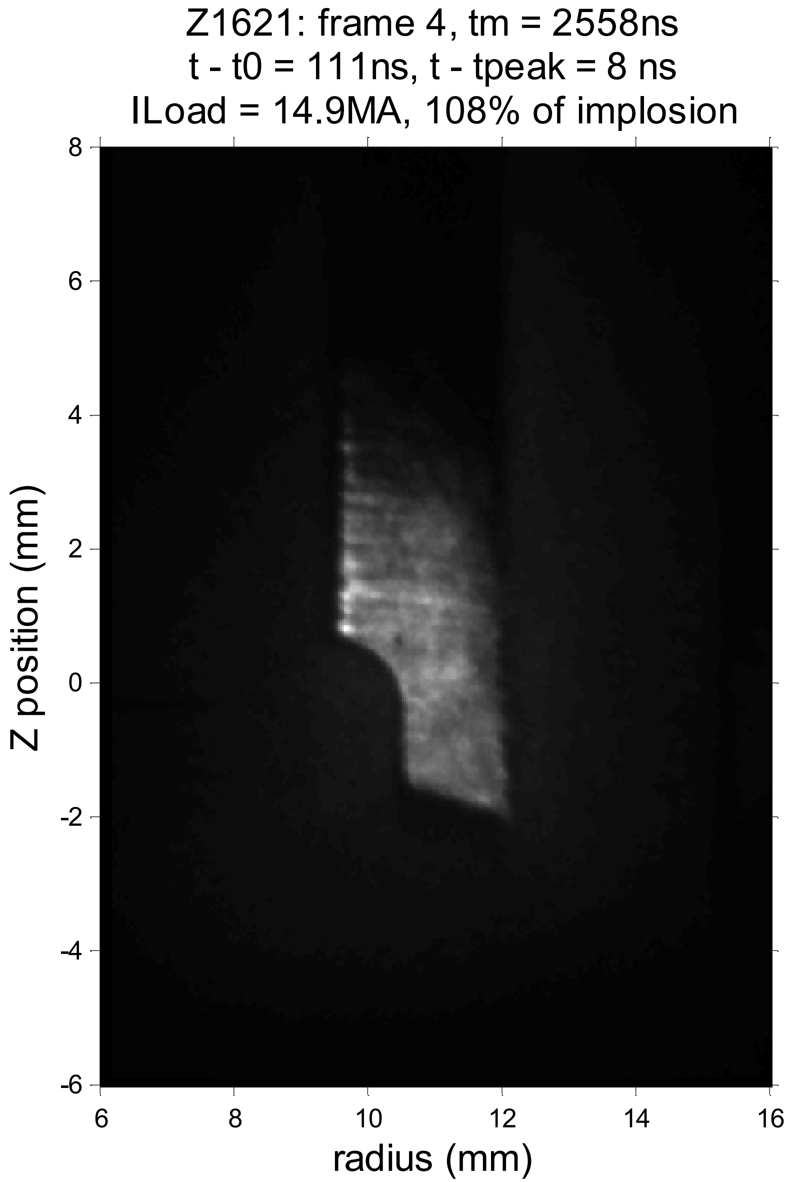
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6

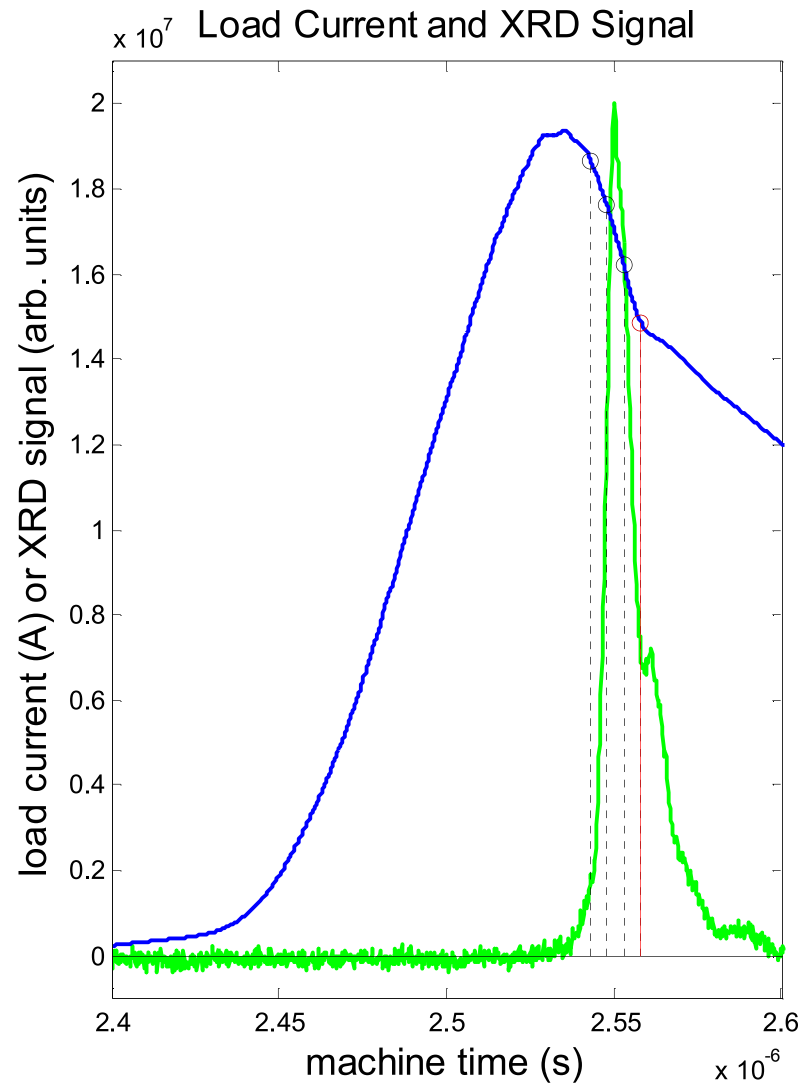


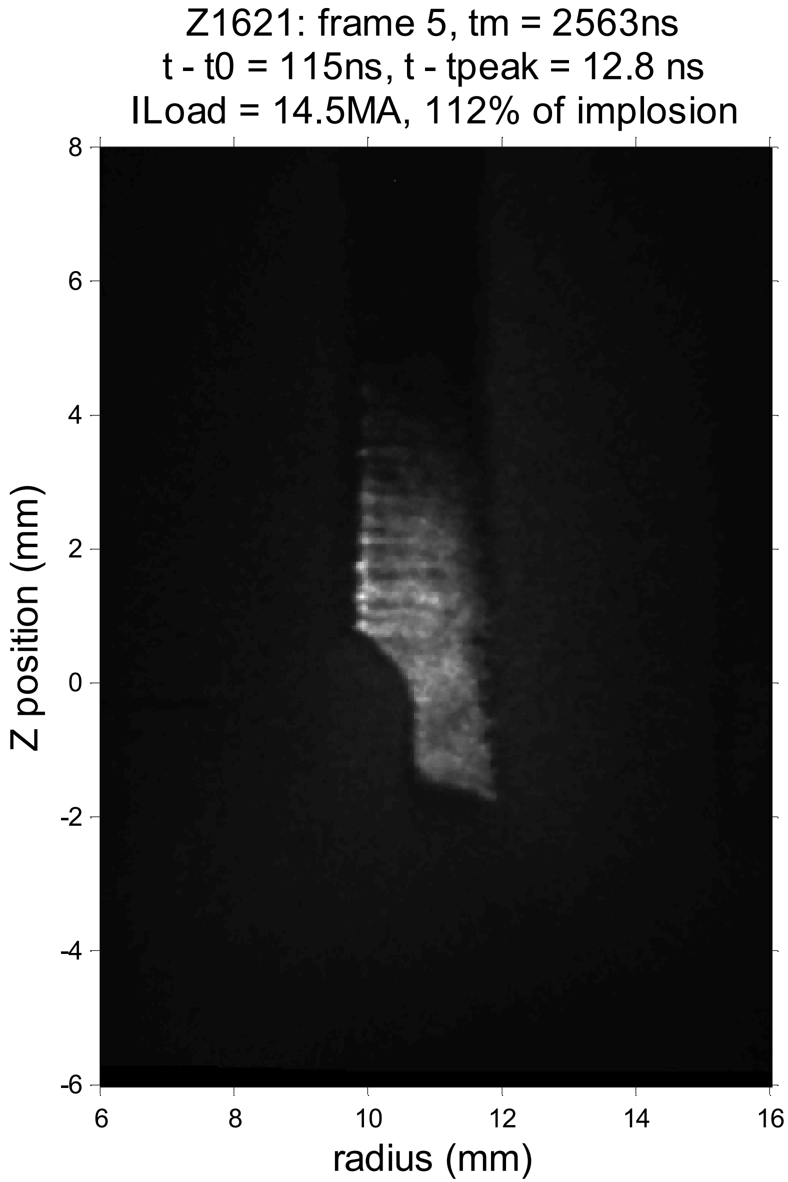
Z1621: frame 3, tm = 2553ns
t - t0 = 105ns, t - tpeak = 2.8 ns
ILoad = 16.2MA, 103% of implosion
Z position (mm)
radius (mm)
8
6
4
2
0
-2
-4
-6
6
8
10
12
14
16



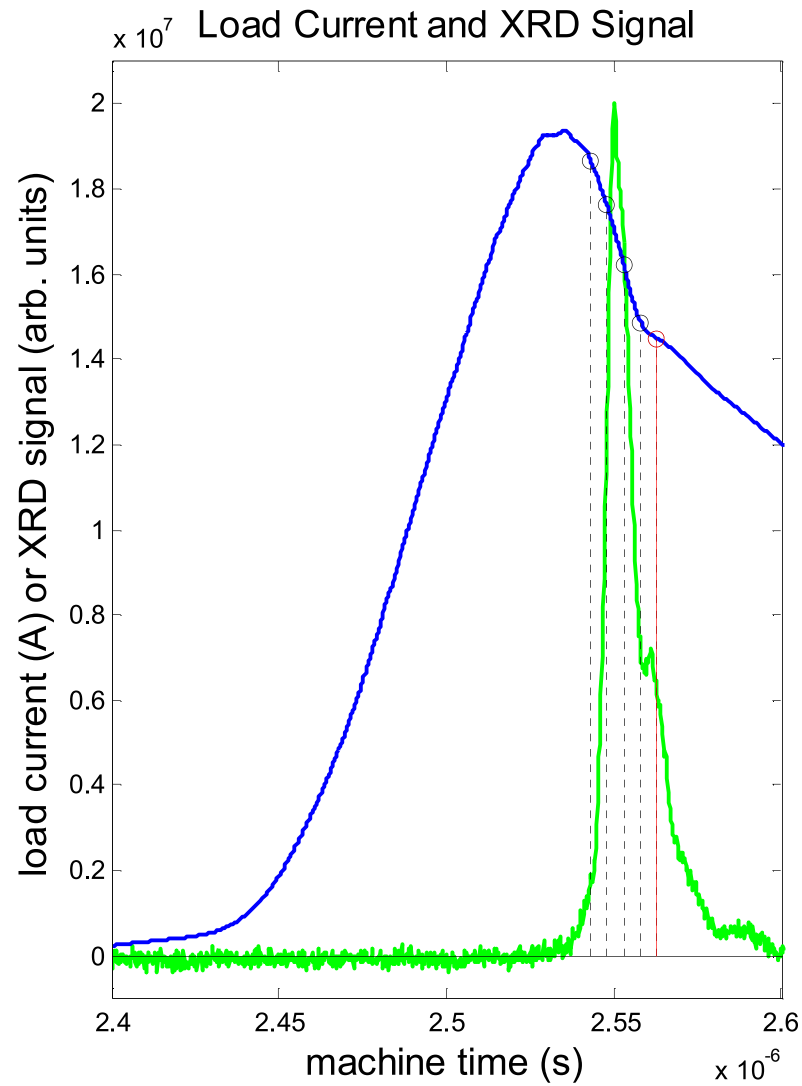
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2.4
2.45
2.5
2.55
2.6


Z1621: frame 4, tm = 2558ns
t - t0 = 111ns, t - tpeak = 8 ns
ILoad = 14.9MA, 108% of implosion
Z position (mm)
radius (mm)

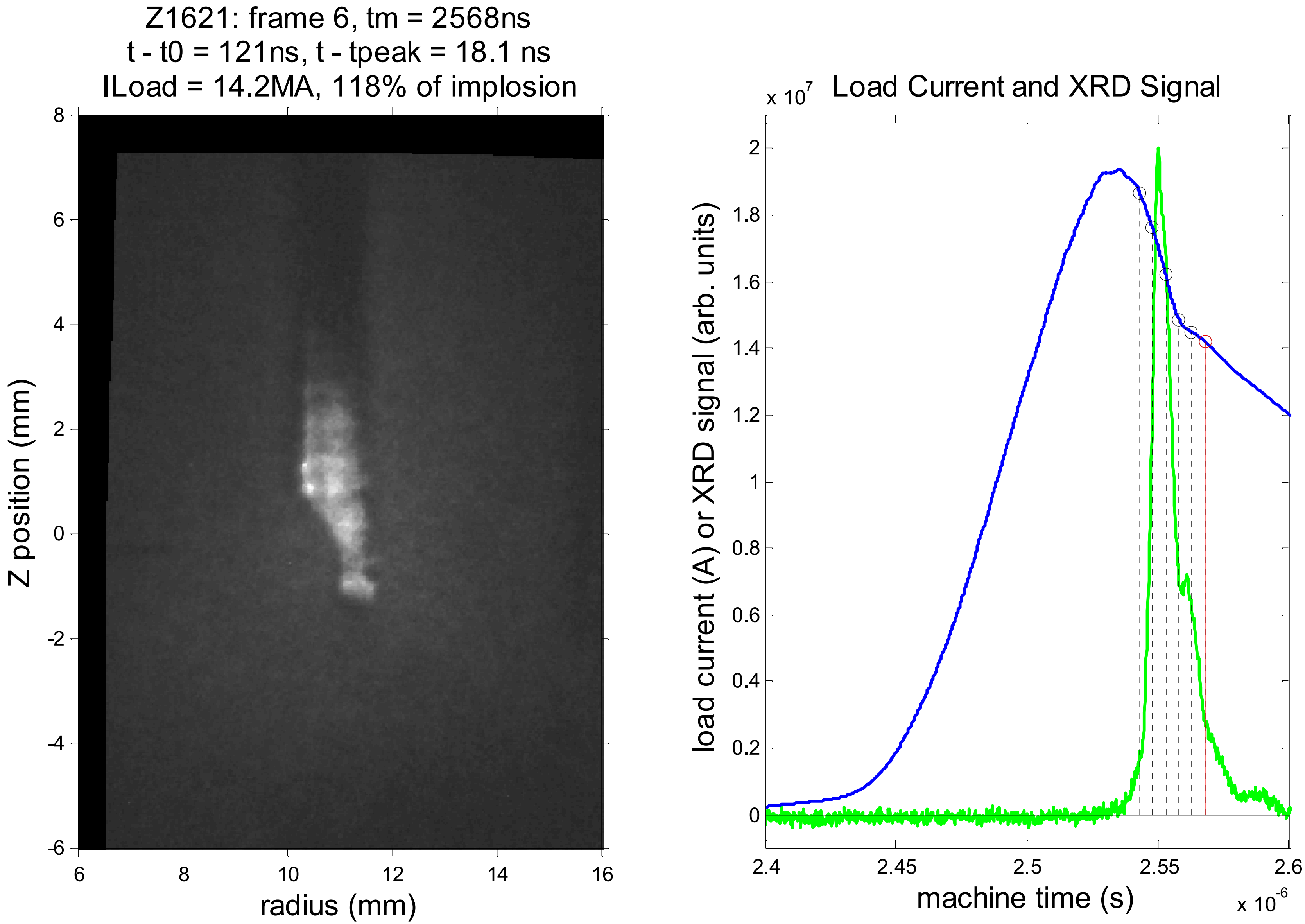

Load Current and XRD Signal
x 10^7
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6



Z1621: frame 5, tm = 2563ns
t - t0 = 115ns, t - tpeak = 12.8 ns
ILoad = 14.5MA, 112% of implosion
Z position (mm)
radius (mm)

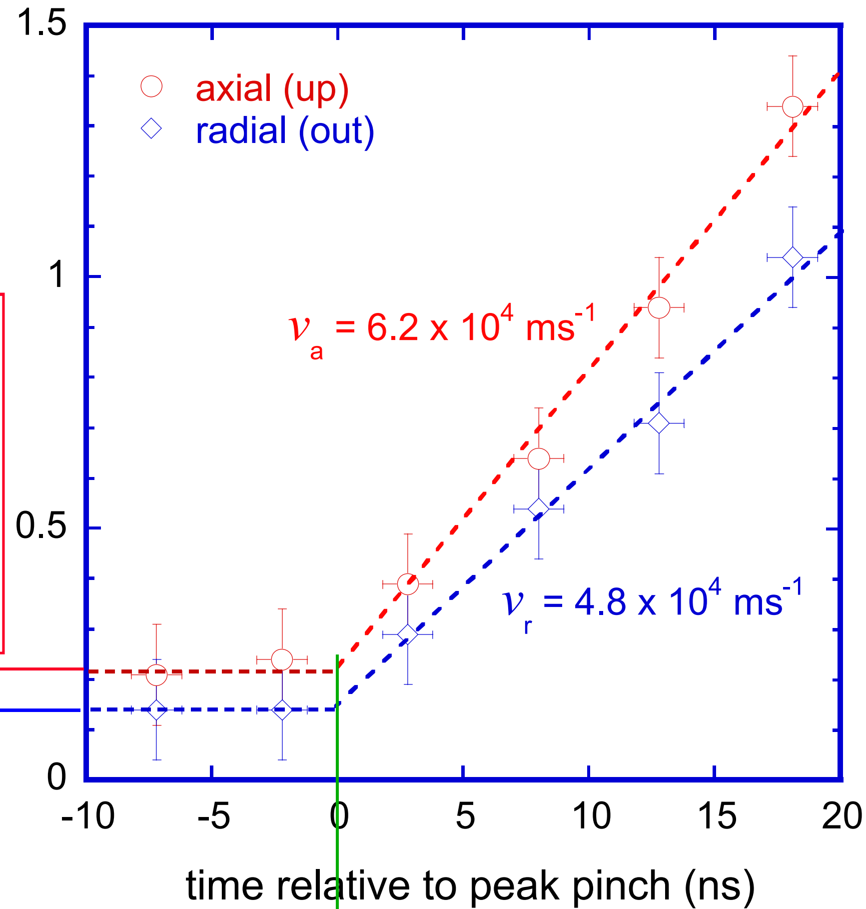


x 10^7
Load Current and XRD Signal
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6



Z1621: frame 6, tm = 2568ns
t - t0 = 121ns, t - tpeak = 18.1 ns
ILoad = 14.2MA, 118% of implosion
Z position (mm)
radius (mm)
Load Current and XRD Signal
x 10^7
load current (A) or XRD signal (arb. units)
machine time (s)
x 10^-6

Plot of Cathode Expansion in the Radial and Axial Directions Versus Time



Upper surface expands 0.21 mm due to power flow and wire motion.

Outer surface expands 0.14 mm due to power flow.

A linear regression of the cathode position after peak pinch extrapolates to the power flow position!

Assuming that the anode expands with a similar radial velocity, $4.8 \times 10^4\ ms^{-1}$, then the observed high density plasma would take ~40 ns after peak pinch to close the 4 mm gap.

Therefore a low density, low gradient plasma must be responsible for shorting the gap at earlier times. The high density plasma serves as a moving surface and source of ions.

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Low density ions and a space charge limited flow could be responsible for the apparent early closure of the gap as compared to the timing of the high density plasma determined from measured velocities.

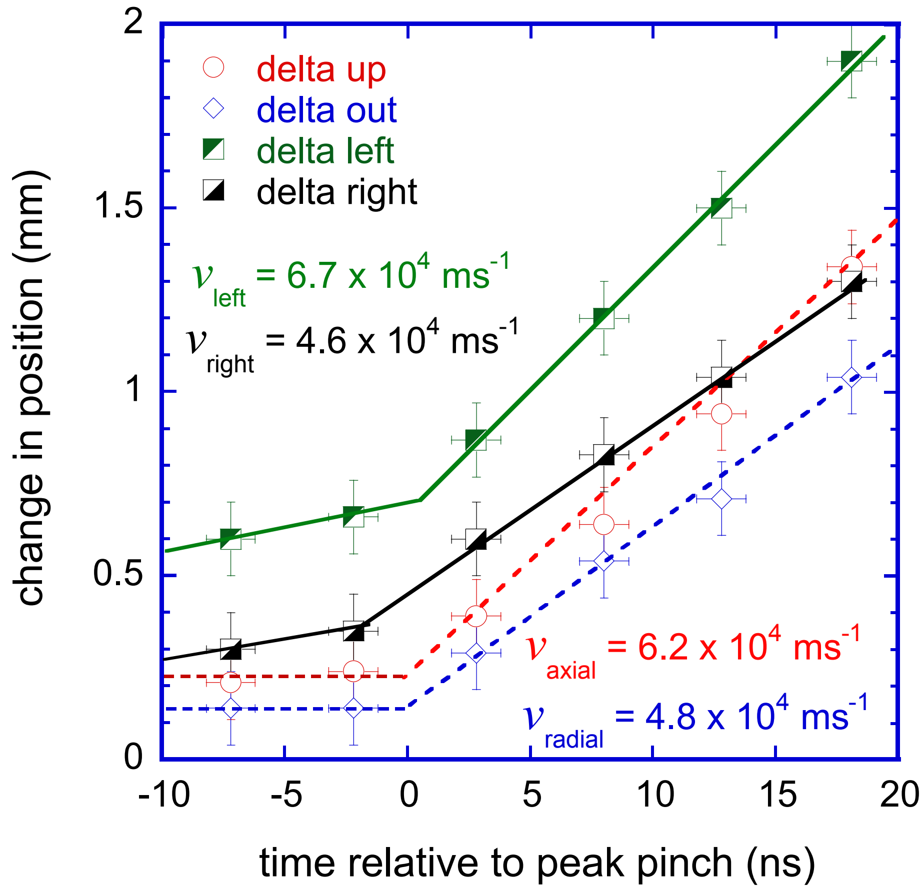
(and you probably thought we were done with ion diodes!)

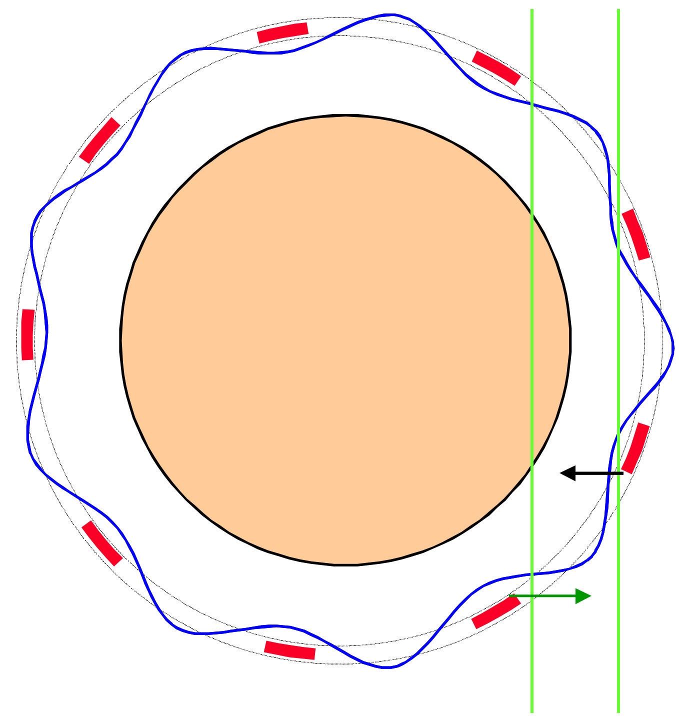
$$J_{CL} \propto \frac{AV^{3/2}}{d^2}$$

Child-Langmuir losses rise sharply as the gap shrinks.

Bryan Oliver has shown that the presence of low density ions, ~10^{14} cm^{-3}, can increase CL flow by factors of 2 or 3. Since the AK gap is bathed in radiation during wire run-in, it is reasonable to expect some ions to fill the gap.

The rate of aperture closure is similar to the cathode expansion rate indicating that the radiation pressure far exceeds the magnetic pressure.





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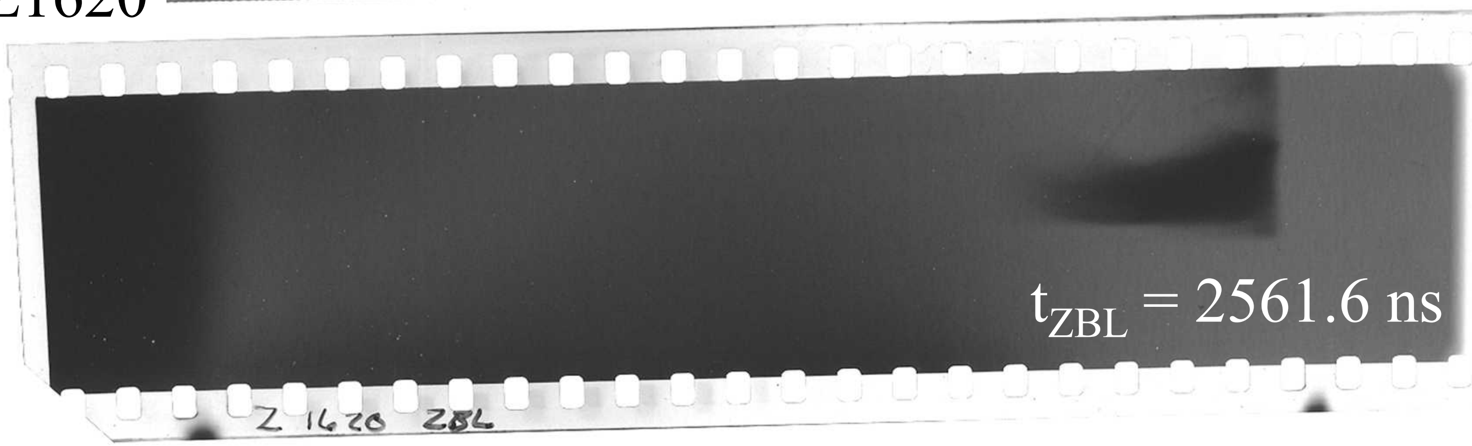
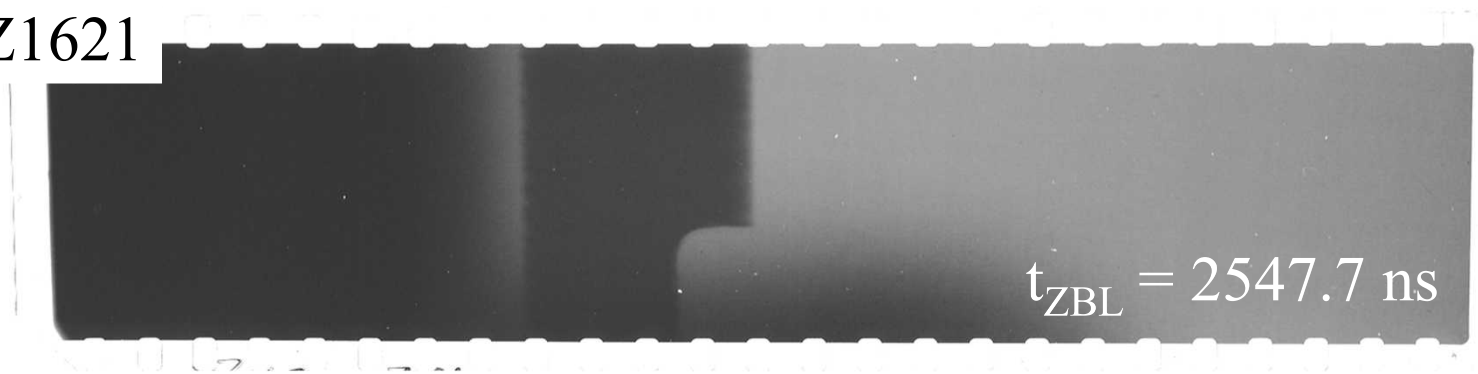
ZBL Image is latest taken on Z of a wire array. We sacrificed the LOS 5/6 to shield the crystal from pinch x-rays. Used XRD’s on LOS 21/22 to get pinch timing.

Z1620



Z1621



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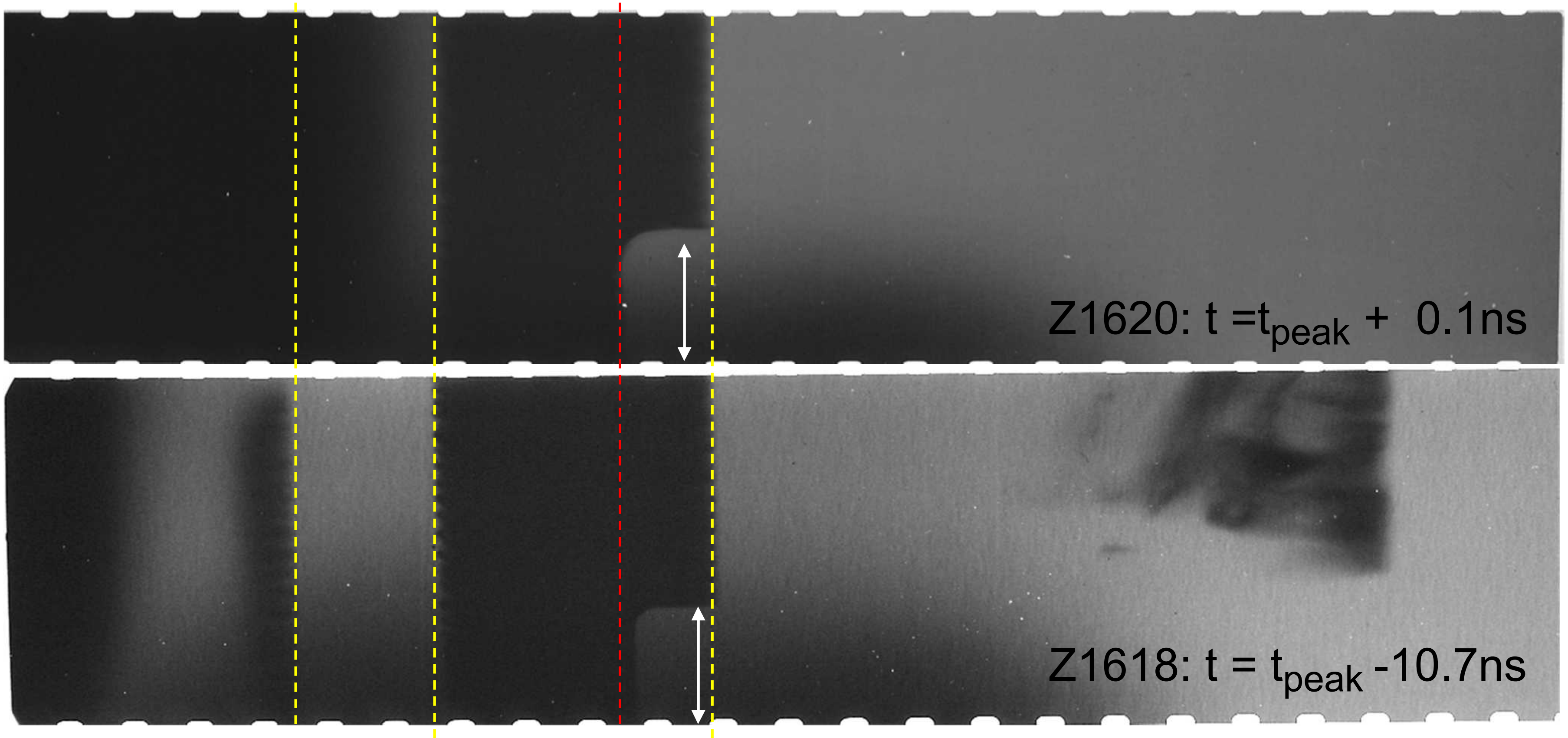
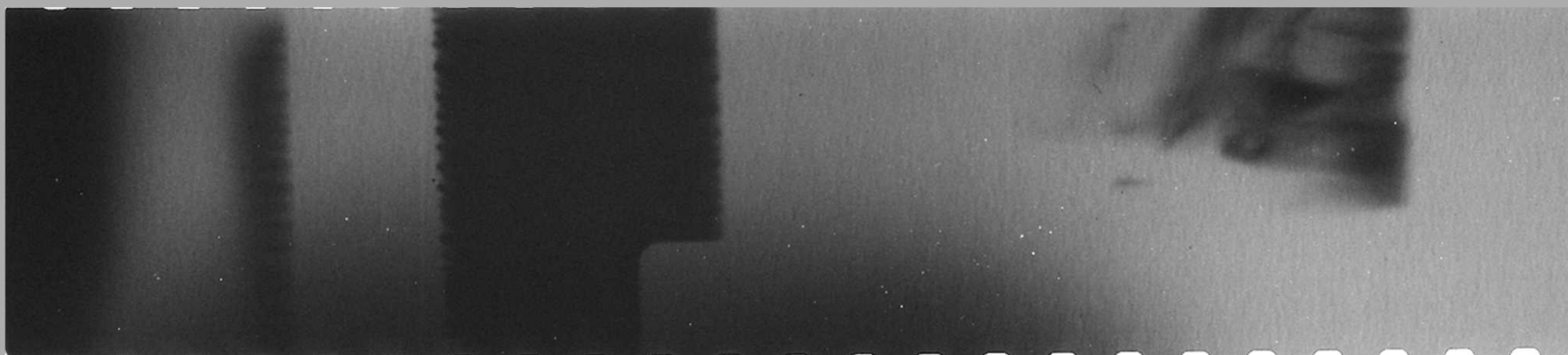
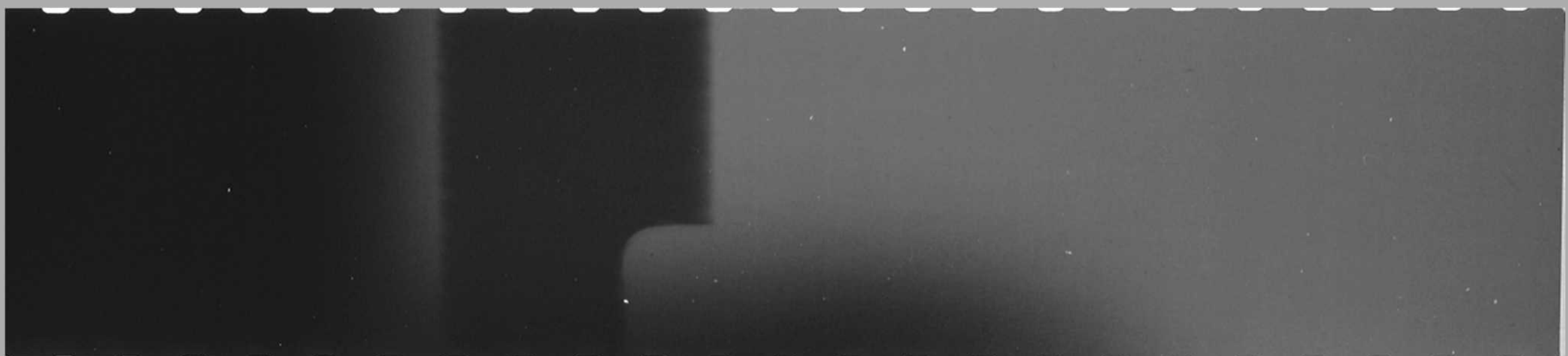
ZBL Images are registered approximately by eye since no pre-shot radiograph was taken.



Z1618: $t = t_{peak}$ -10.7ns

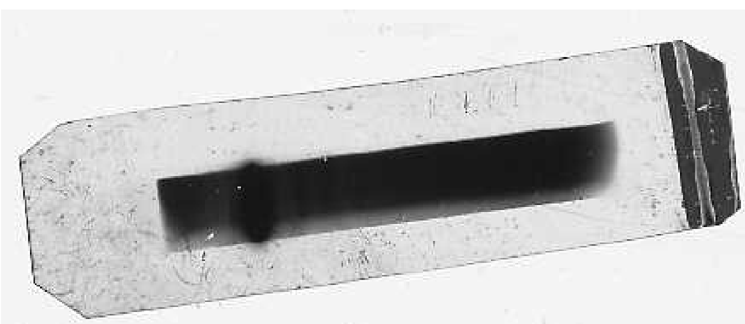


Z1620: $t = t_{peak} + 0.1ns$



Results from University Spectrometers fielded in the chamber.

- Film from Reno spectrometer totally saturated. Victor needs a shutter and some method to attenuate the x-rays.

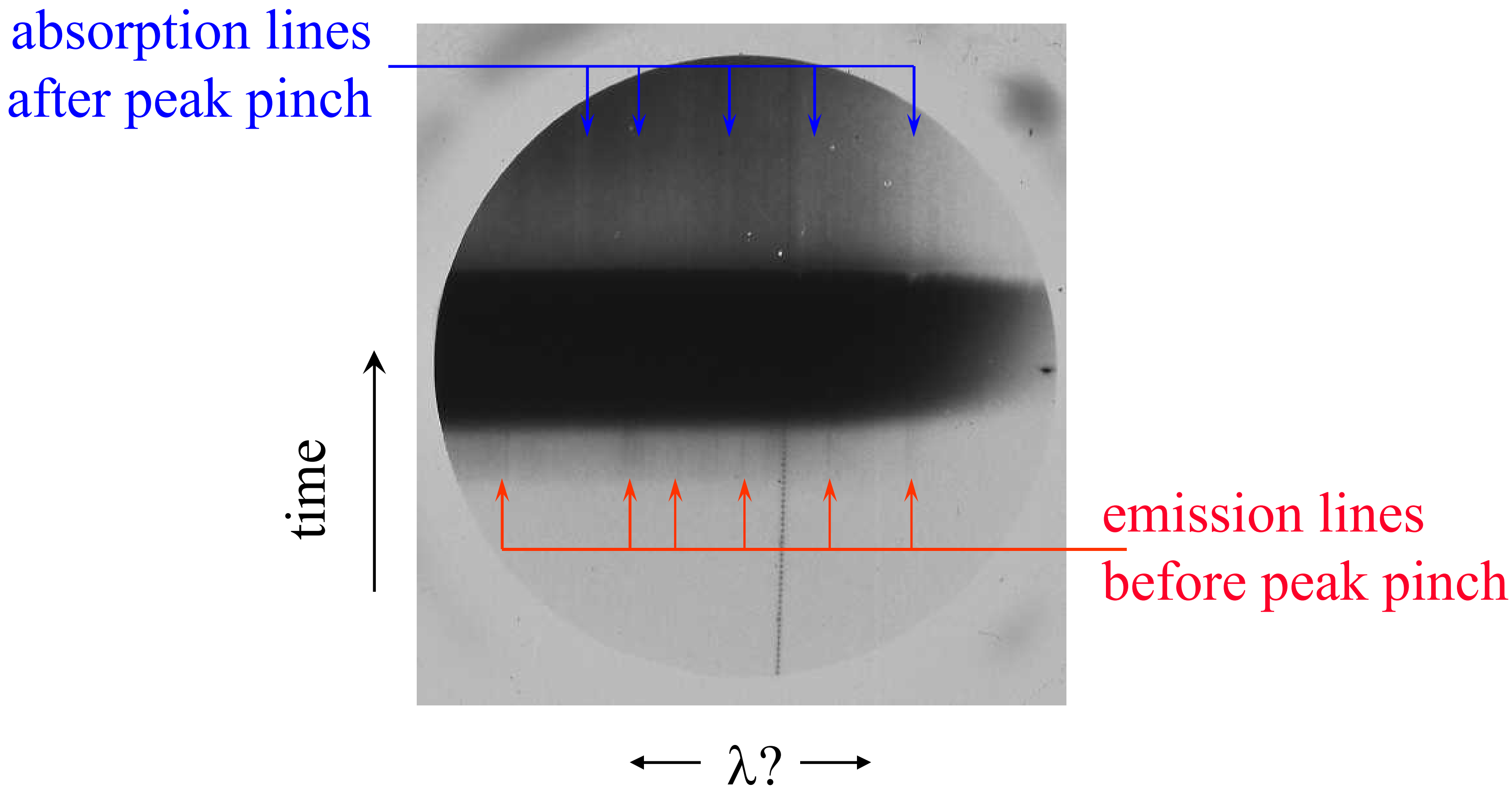


- Film from BYU spectrometer is overexposed, but lines can be discerned. Sasha Shvelko will collaborate to analyze the spectrum.

Streaked VUV Spectrometer

Got Lines!

(This should make Yitzhak happy but that's about it at this point)



Summary

Framing camera images indicate that a dense plasma is driven across the gap at a radial velocity of order $5x10^4$ m/s.

Before peak pinch, a small expansion of the cathode of order 100um is observed which is due to power flow and wire array motion.

Many other small successes: In chamber university spectrometers, latest time for a ZBL image of an open Z-pinch