Wire array response to current risetime variation on COBRA using laser-triggered switching

J. B. Greenly, J. D. Douglass, D.A. Chalenski,
D.A.Hammer, B.R. Kusse, R.D. McBride,
L.M.Maxson, H.W. Wilhelm

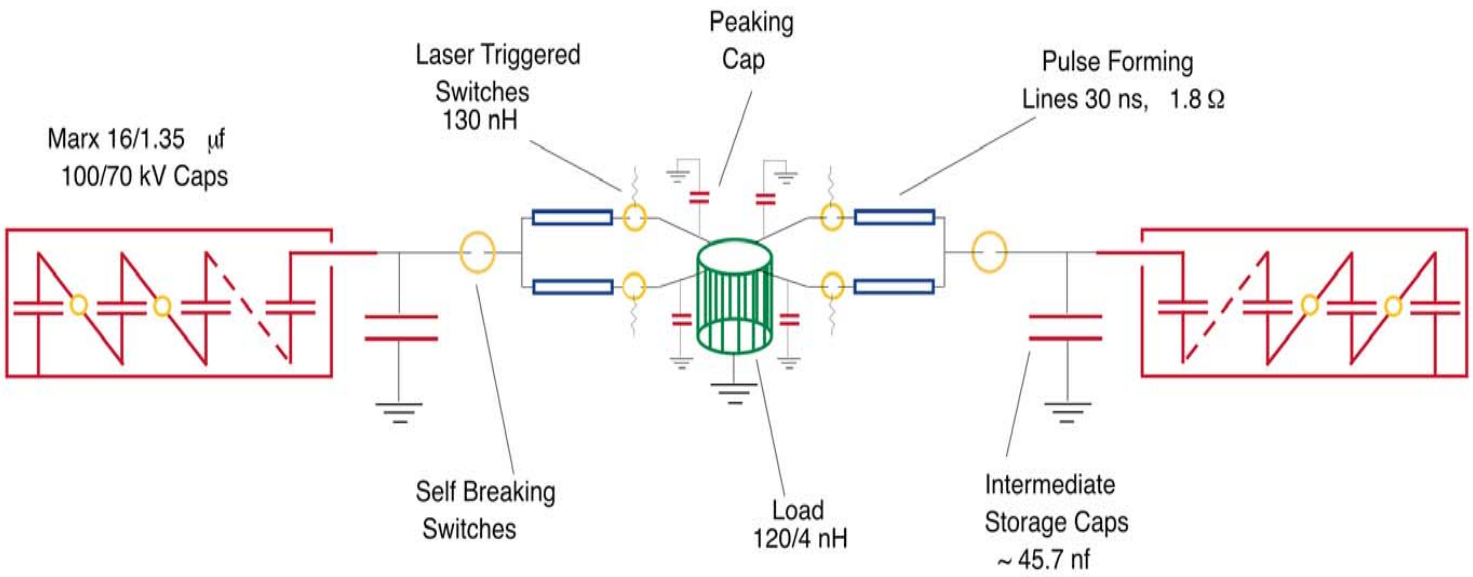
Laboratory of Plasma Studies, Cornell University

--Brief introduction to the hardware: COBRA

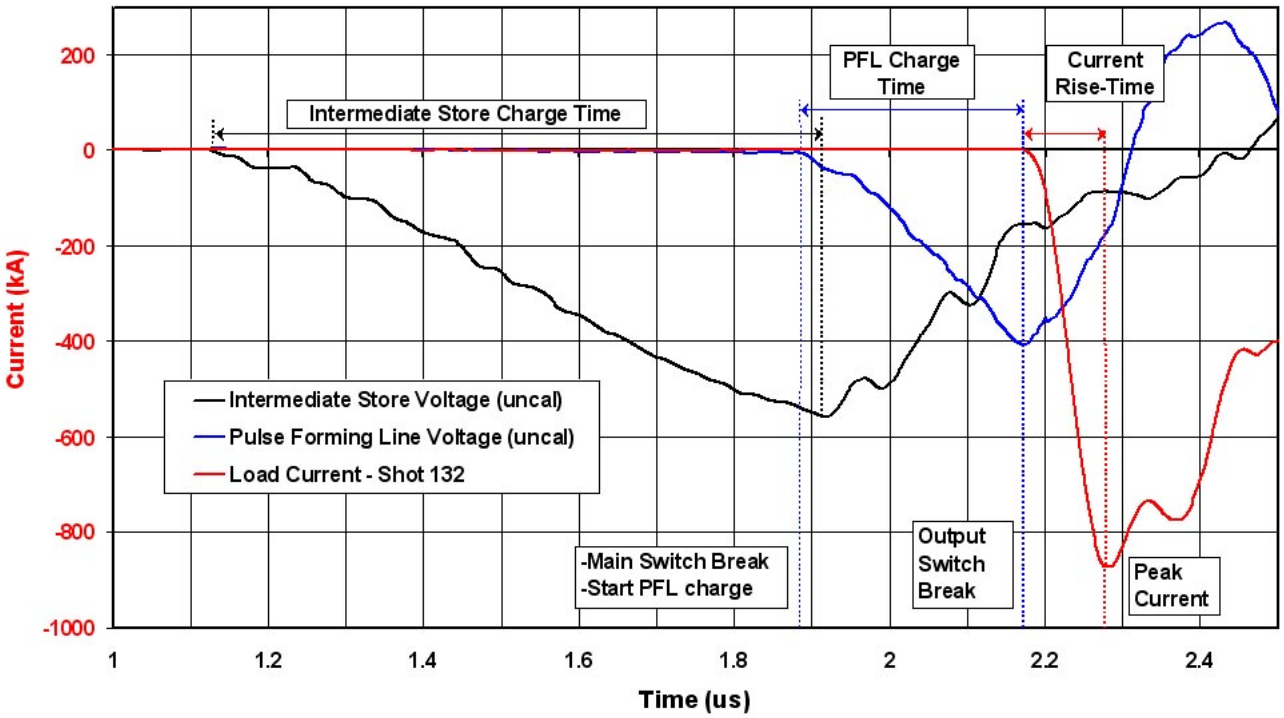
--Illustration of variety of waveforms available with laser-triggered switching of COBRA's four PFLs.

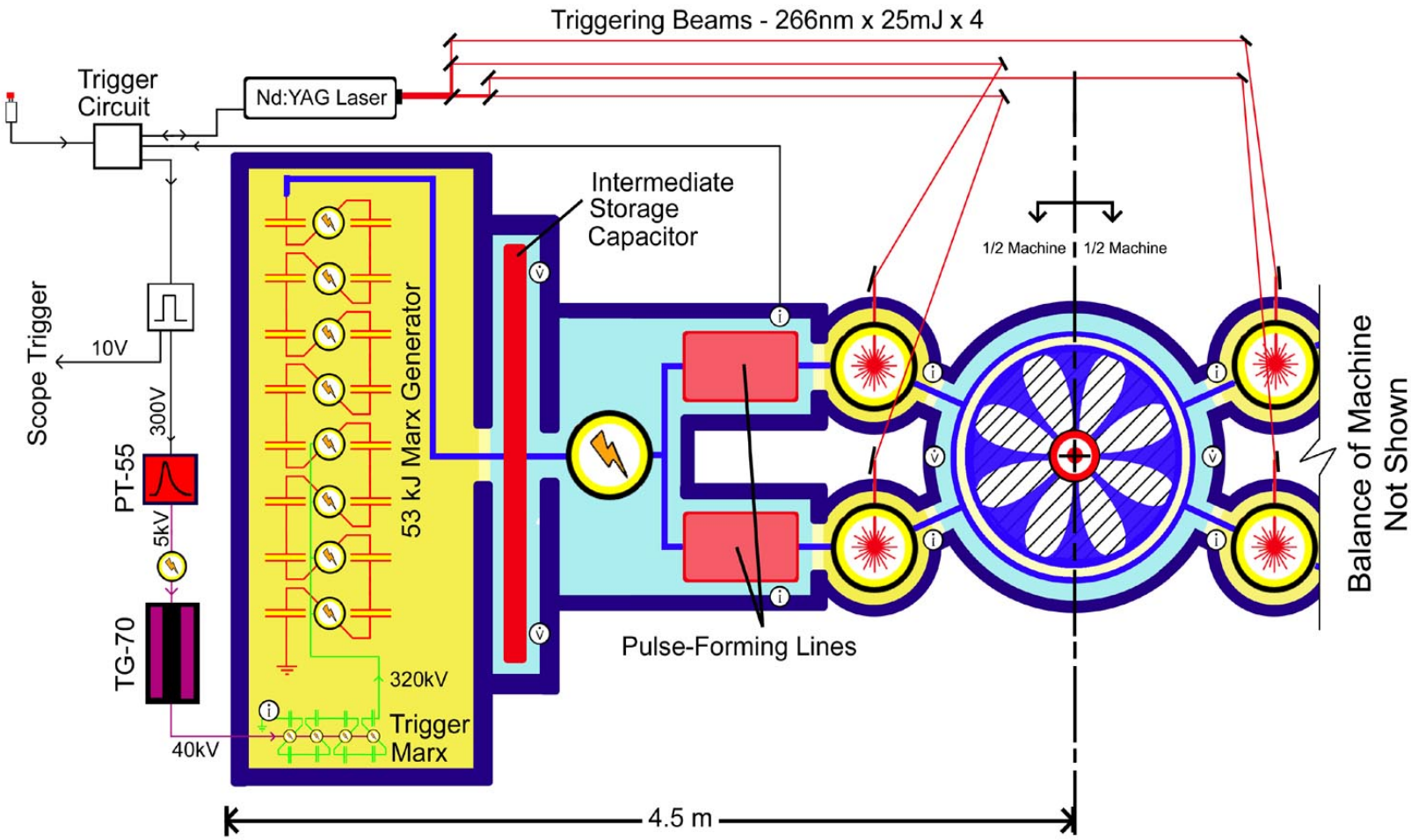
--Data: impedance measurements of 8 wire, 12.5μm aluminum arrays.

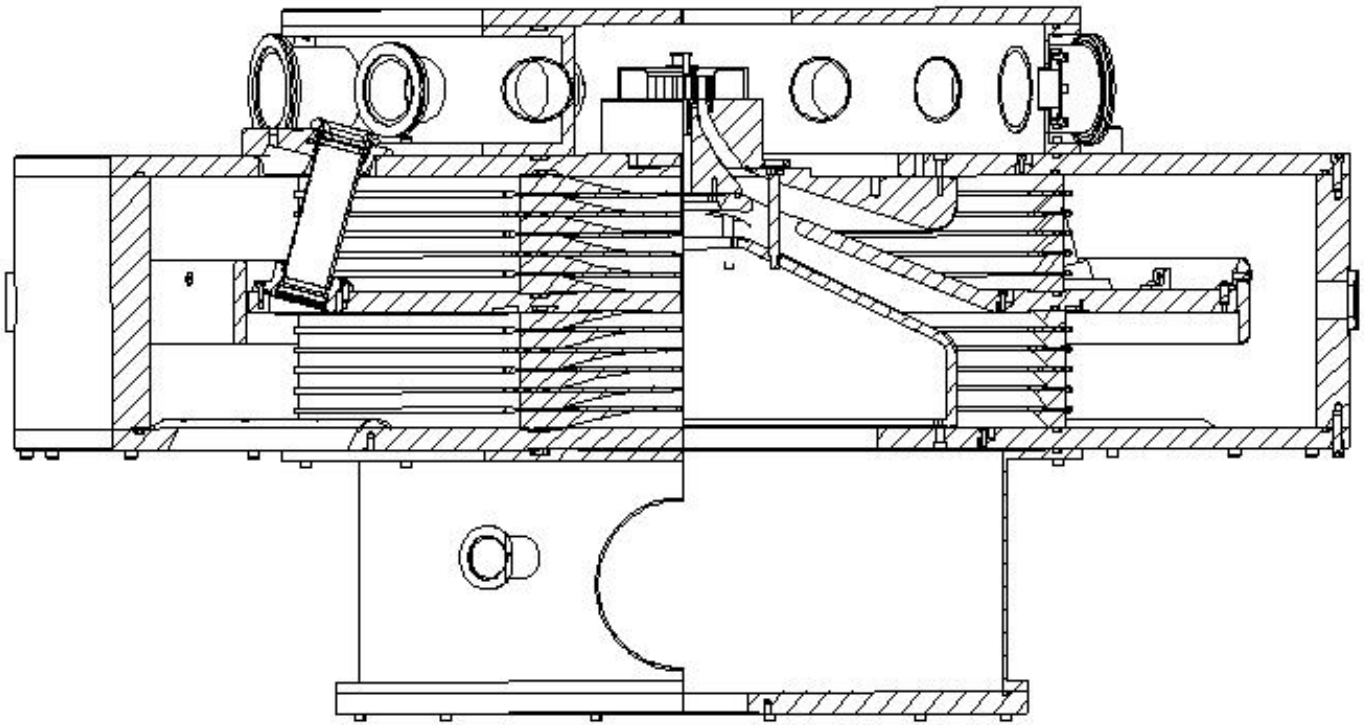
COBRA


Marx 16/1.35 μf
100/70 kV Caps
Laser Triggered
Switches
130 nH
Peaking
Cap
Pulse Forming
Lines 30 ns, 1.8 Ω
Self Breaking
Switches
Load
120/4 nH
Intermediate
Storage Caps
~ 45.7 nf

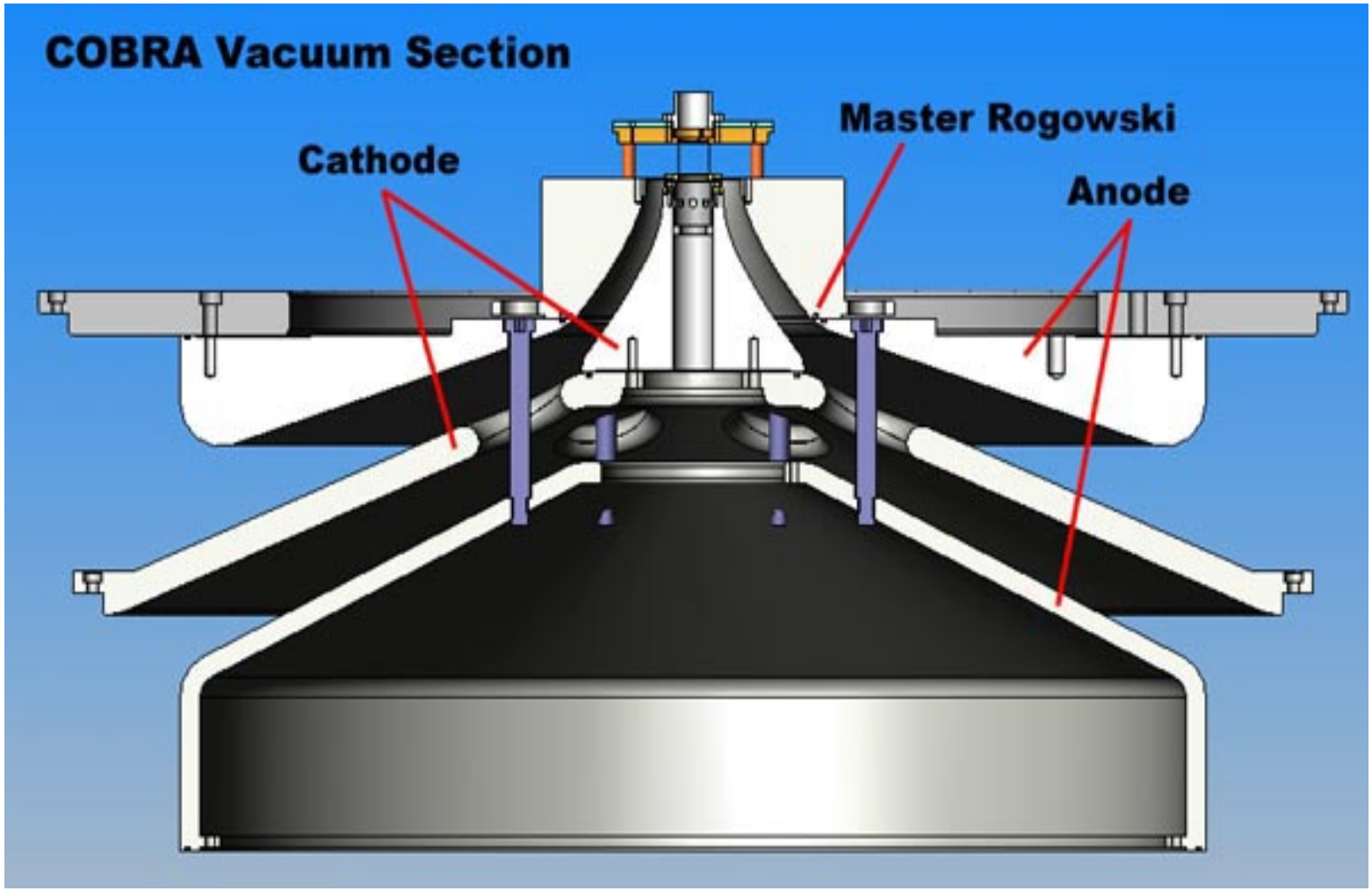
COBRA charging and output waveforms:

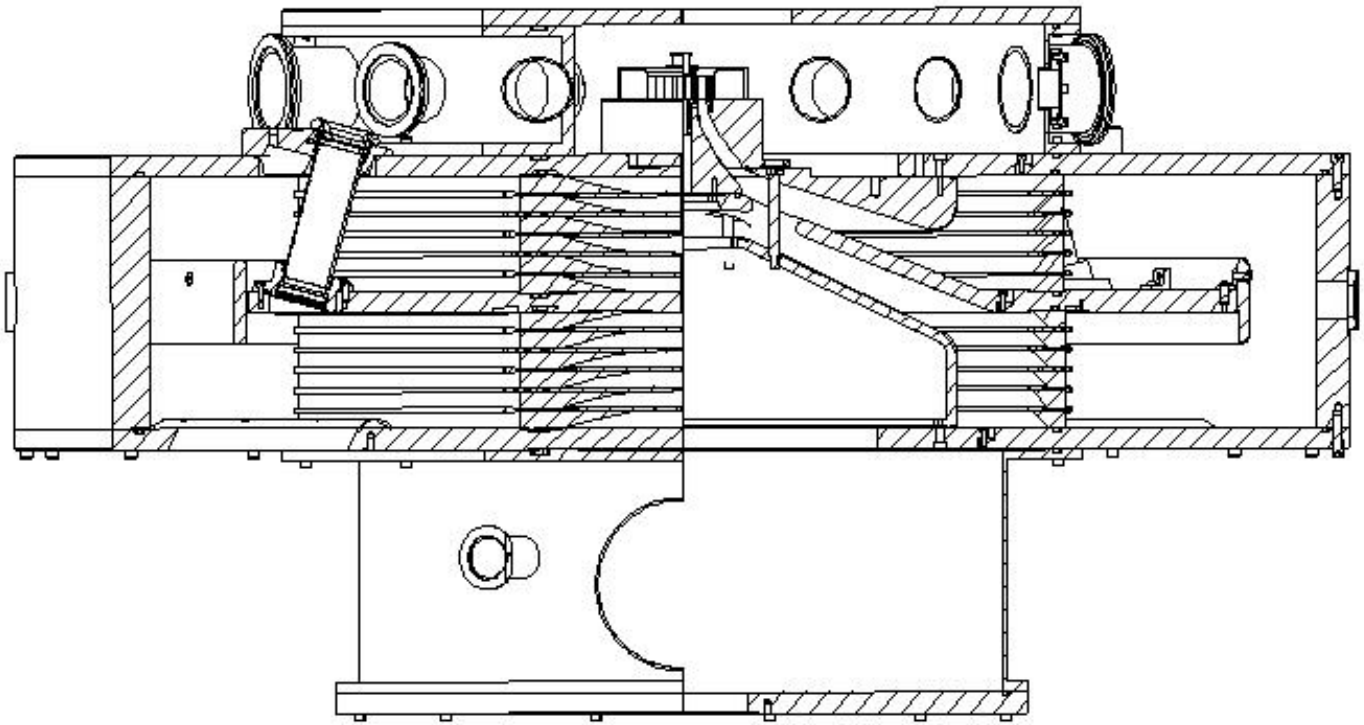


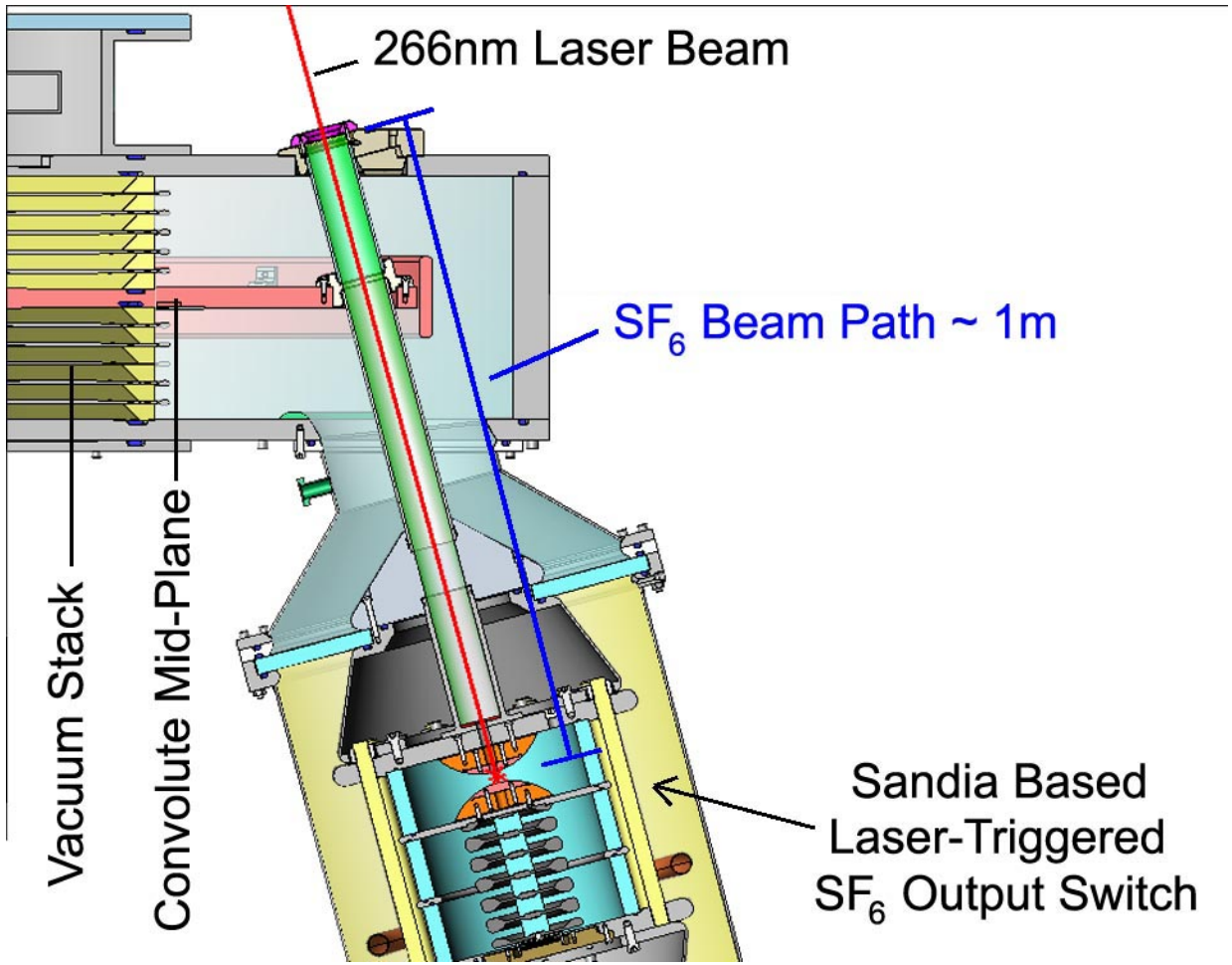

Triggering Beams - 266nm x 25mJ x 4
Trigger Circuit
Nd:YAG Laser
Intermediate Storage Capacitor
1/2 Machine
1/2 Machine
Scope Trigger
10V
300V
PT-55
5kV
TG-70
40kV
53 kJ Marx Generator
320kV
Trigger Marx
Pulse-Forming Lines
Balance of Machine Not Shown
4.5 m



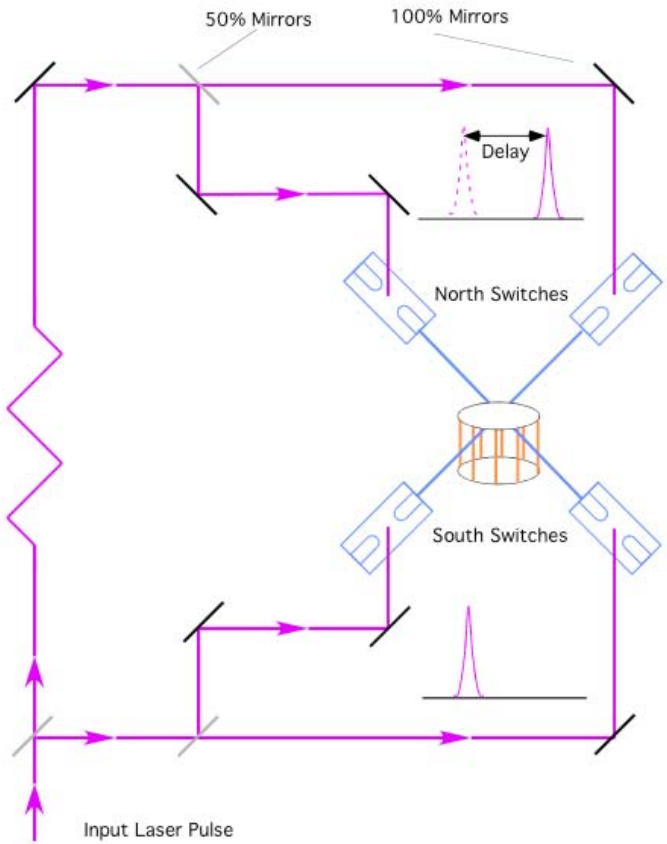
COBRA final water/vacuum interface, MITL convolute, load and diagnostic access.

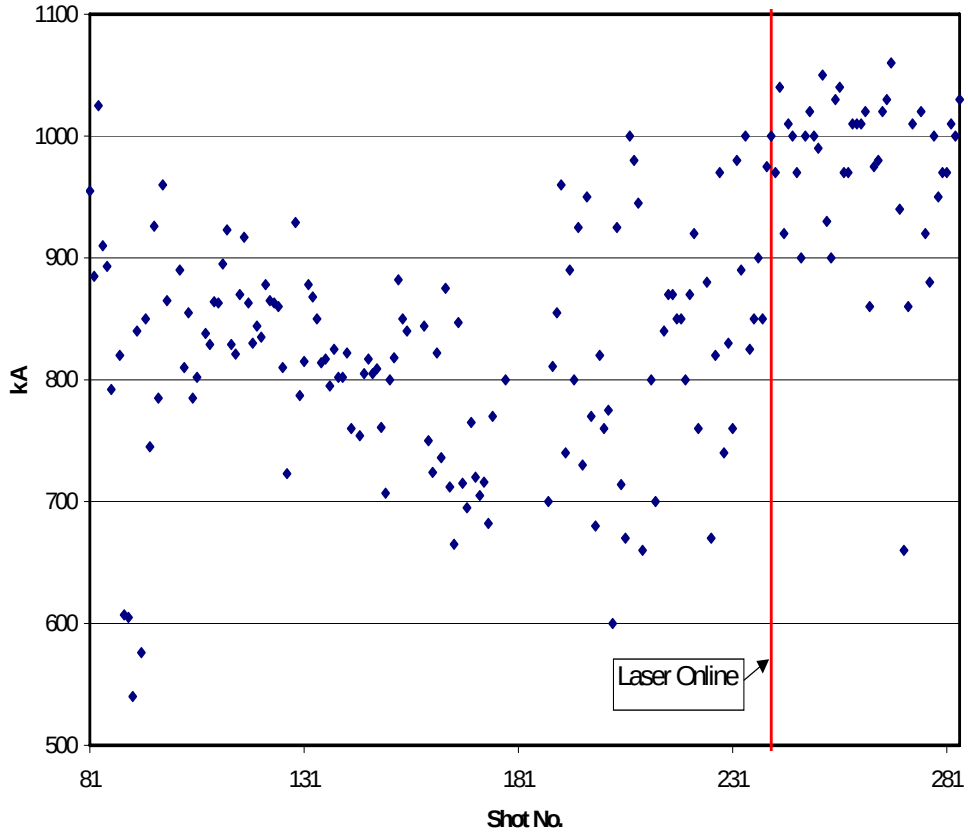

COBRA Vacuum Section
Cathode
Master Rogowski
Anode




266nm Laser Beam
SF6 Beam Path ~ 1m
Vacuum Stack
Convolute Mid-Plane
Sandia Based
Laser-Triggered
SF6 Output Switch

Laser Triggering for COBRA Pulse-Shaping



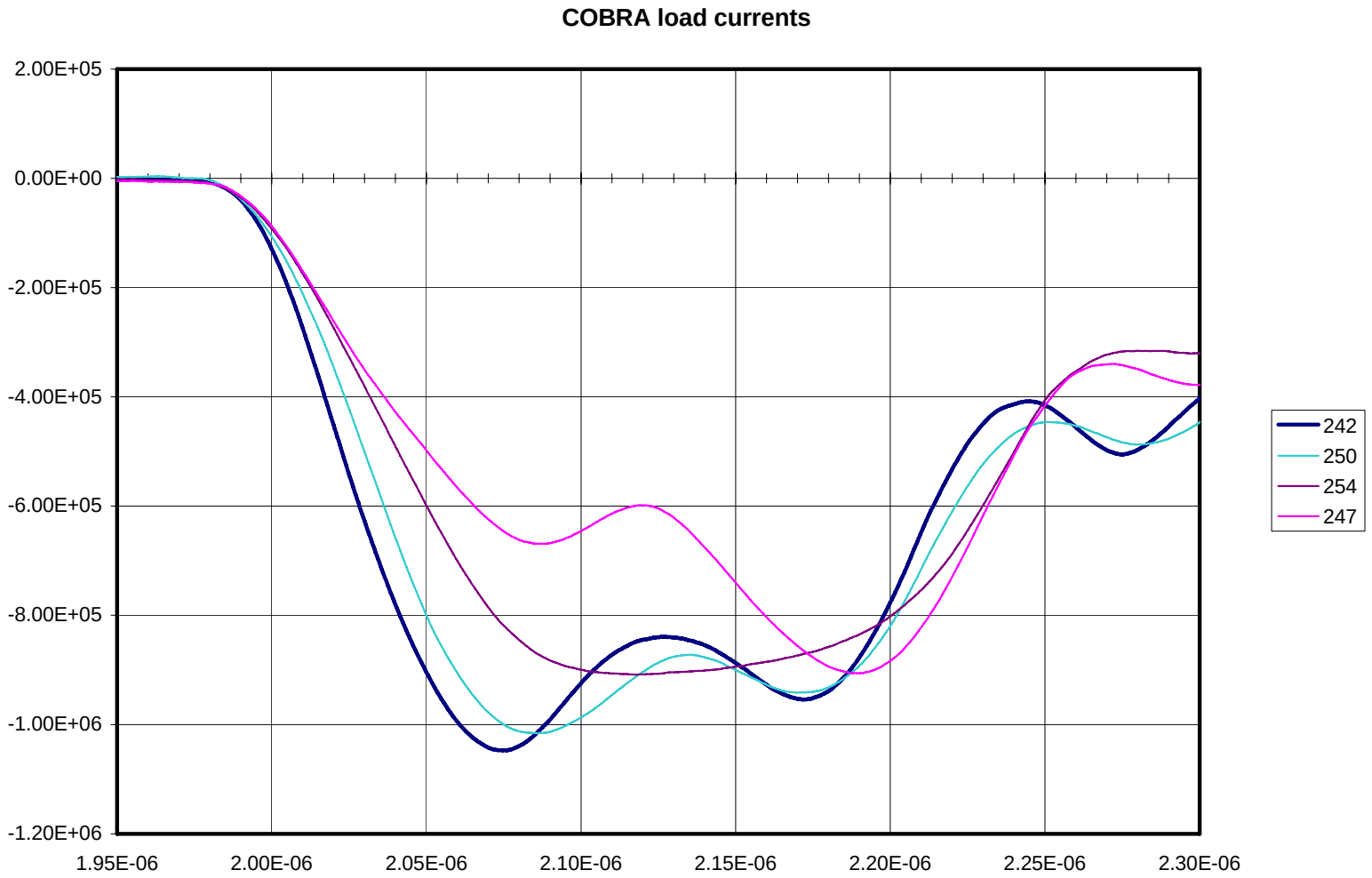


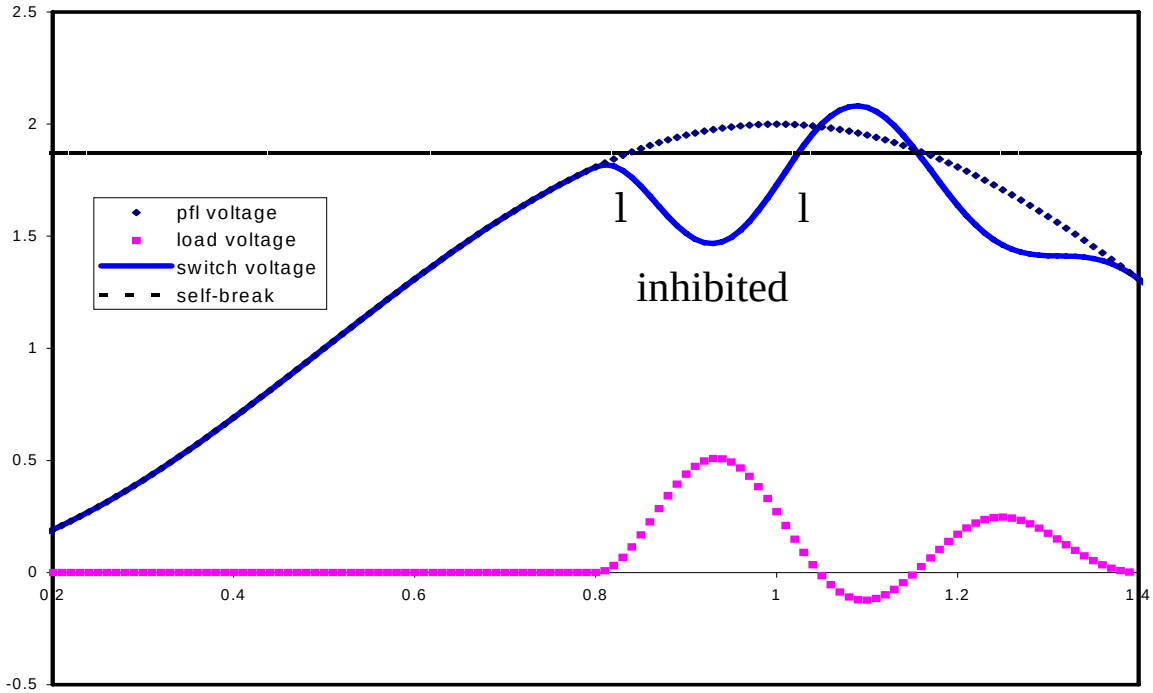
Switch closure time from start of laser pulse:

14-18 ns @ 80% self-break,

20-25 ns @ 70% self-break.

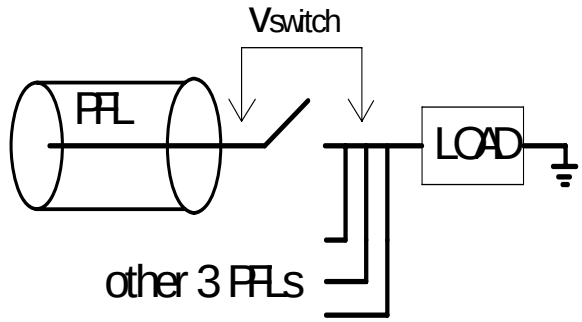
Below 70% of self-break: longer times, larger variation


COBRA load currents
2.00E+05
0.00E+00
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
-1.00E+06
-1.20E+06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
2.25E-06
2.30E-06
242
250
254
247



After some of the PFLs switch out, the others are inhibited from self-breaking.

The laser can trigger them during the inhibited interval.



COBRA load voltage and current diagnostics enable good accounting of energy dissipated in the load:

-- voltage during wire initiation: consistent with low-voltage single wire experiments.

-- magnetic energy: integral of I*LIdot (=1/2 LI^2)

-versus-

integral of I*(V - LIdot) --Ldot and resistive voltage

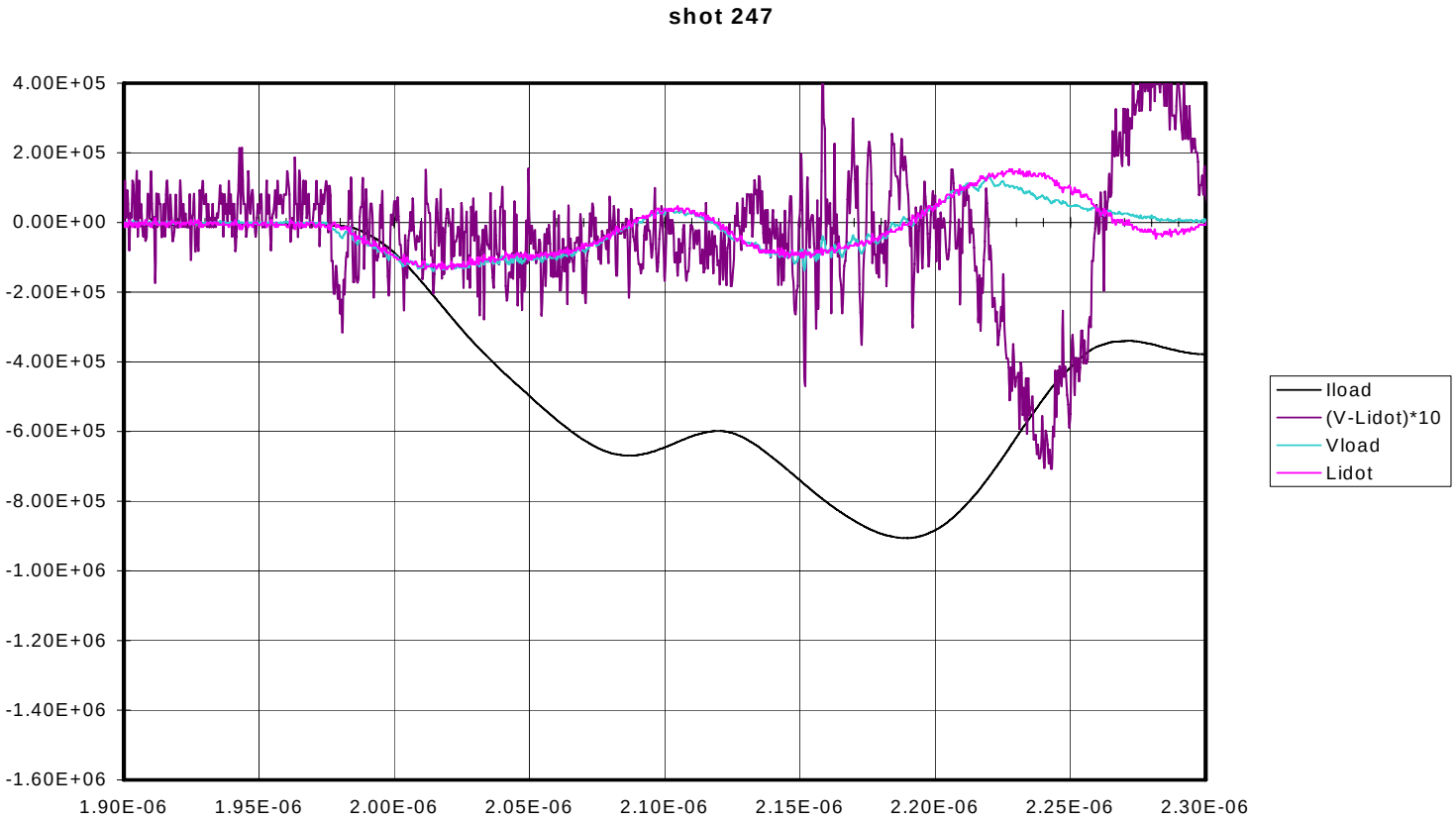
COBRA has no significant prepulse:

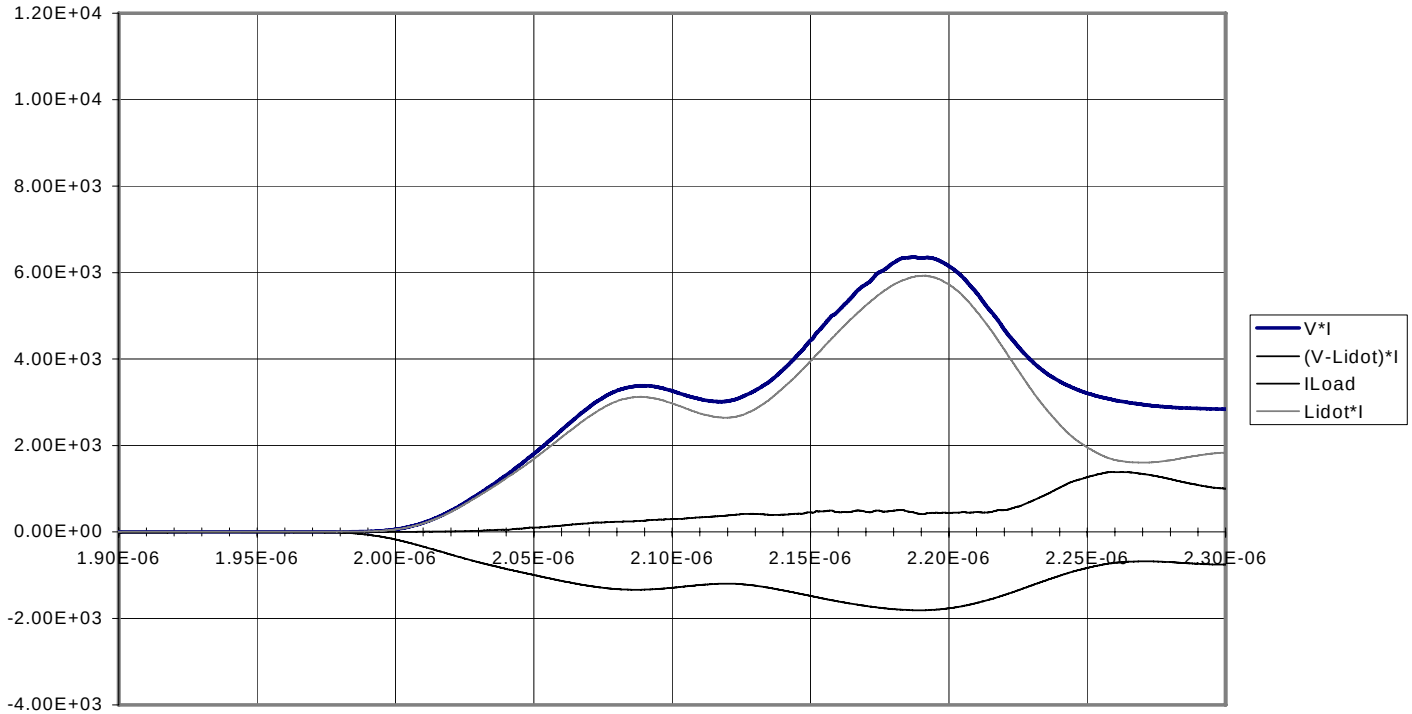
< 5 kV upper limit from voltage monitor

wire initiation:

The voltage monitor sees a ~20 kV, ~ 5-10 ns pulse that corresponds to the resistive heating phase of the wires (This demonstrates that prepulse has not already ionized the wires).

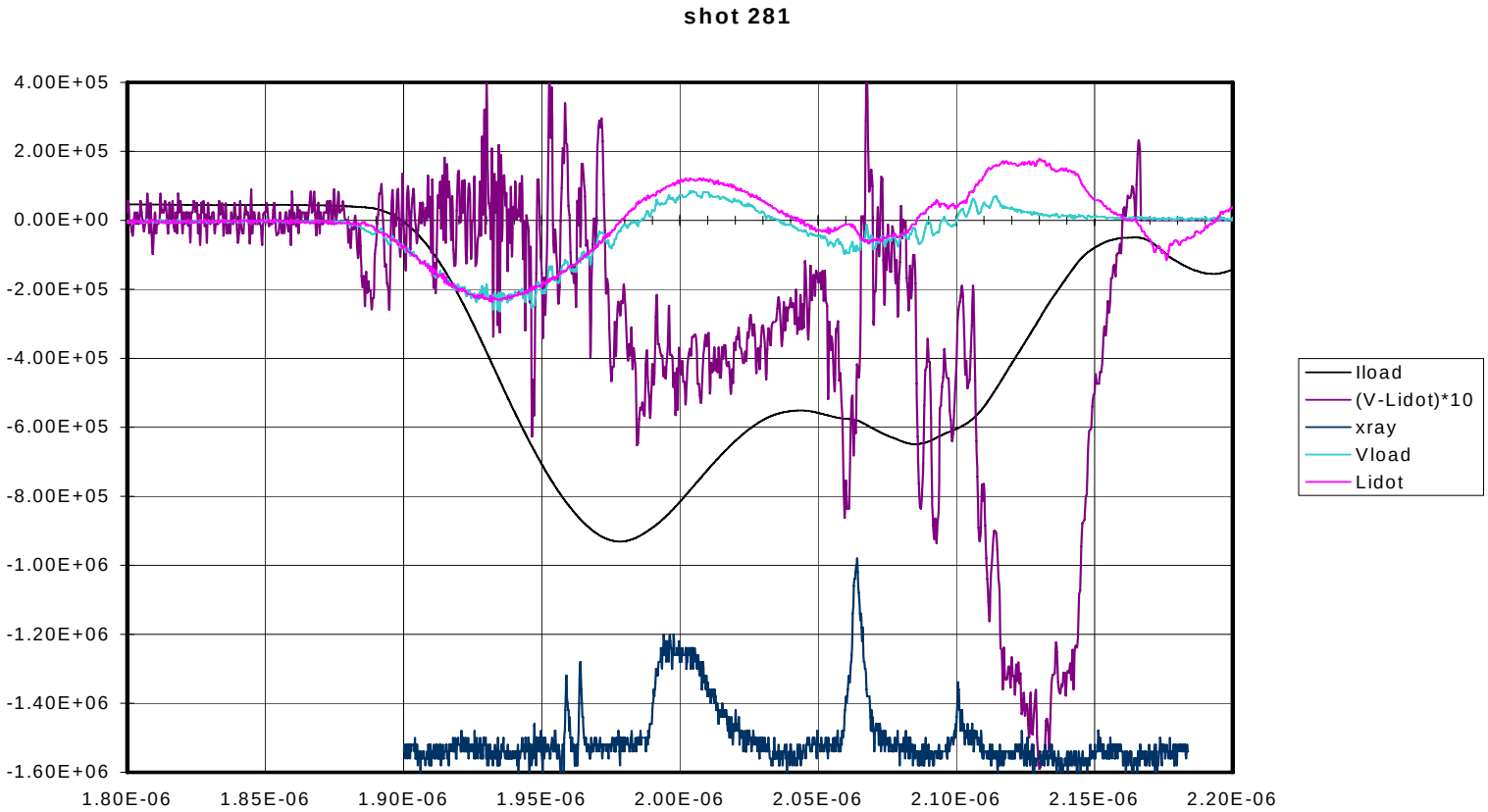
Heavy array: no implosion, V ~ LIdot

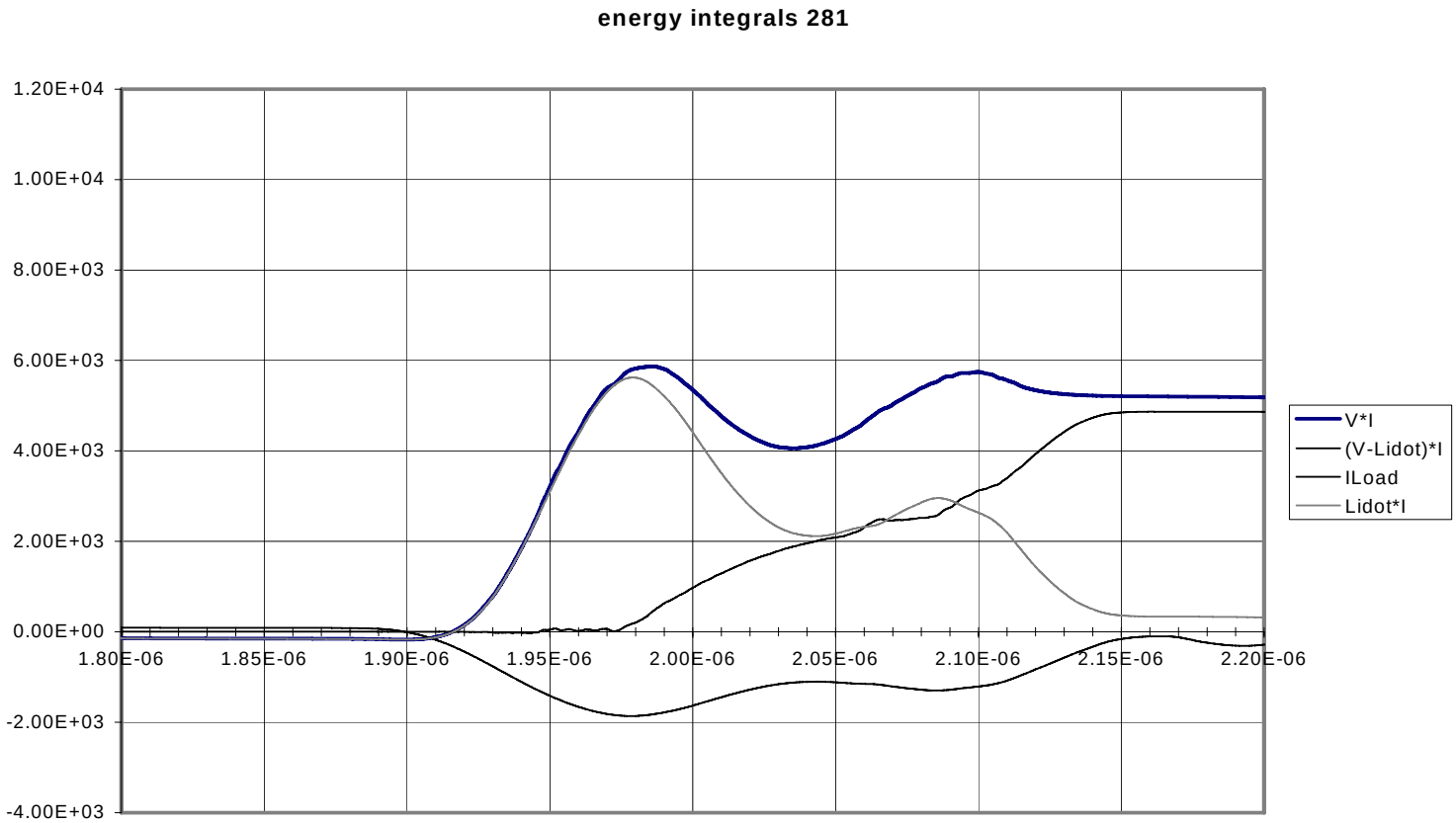



energy integrals 247
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
-2.00E+03
-4.00E+03
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
2.25E-06
2.30E-06
V*I
(V-Lidot)*I
ILoad
Lidot*I

Fast current rise: matched load mass, good pinch:

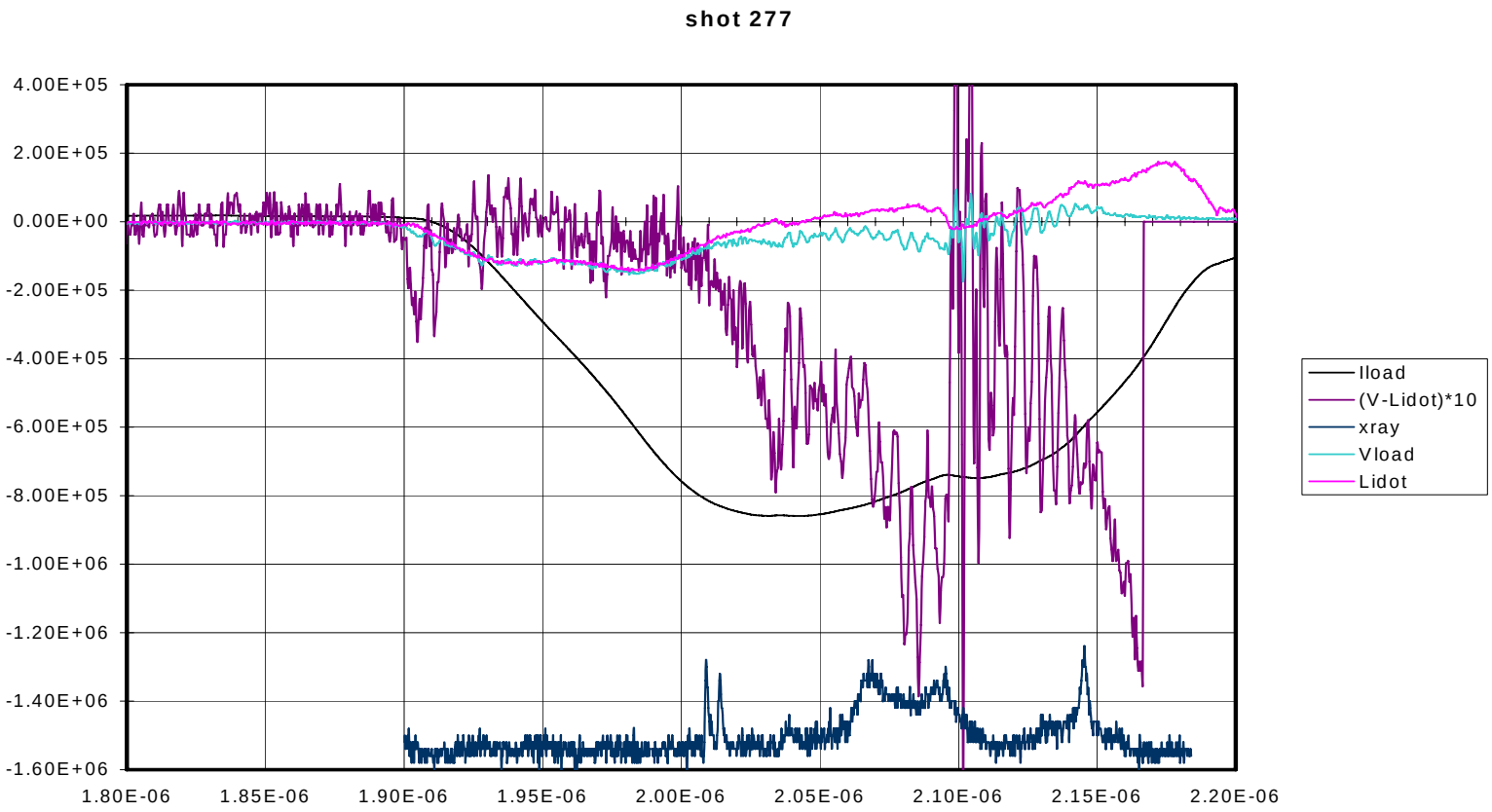
(V-LIdot) rises just before x-ray pulse

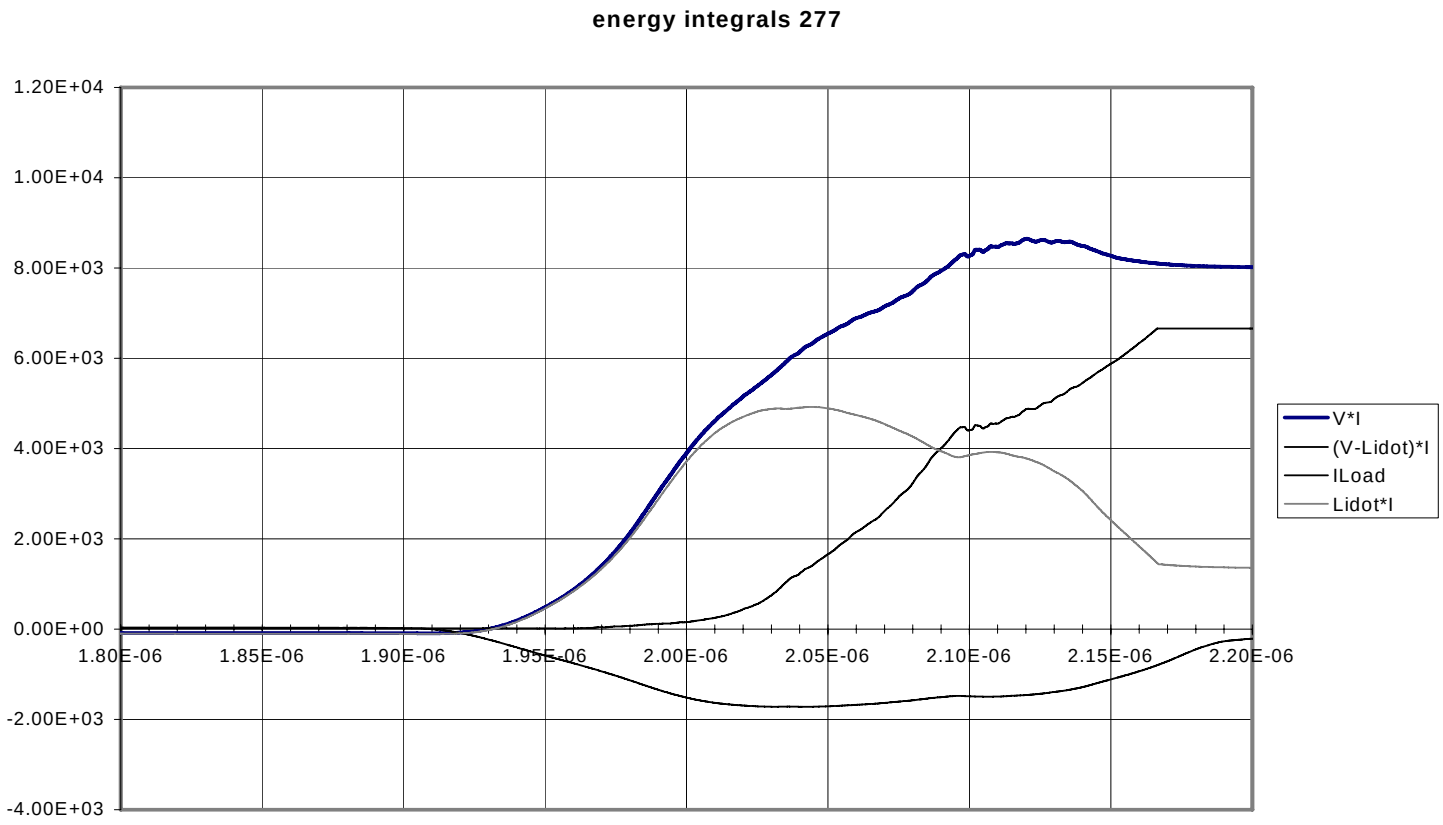



energy integrals 281
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
-2.00E+03
-4.00E+03
1.80E-06
1.85E-06
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
V*I
(V-Lidot)*I
ILoad
Lidot*I

Slower current rise: later pinch, lower x-ray power

different voltage characteristic: long slow rise

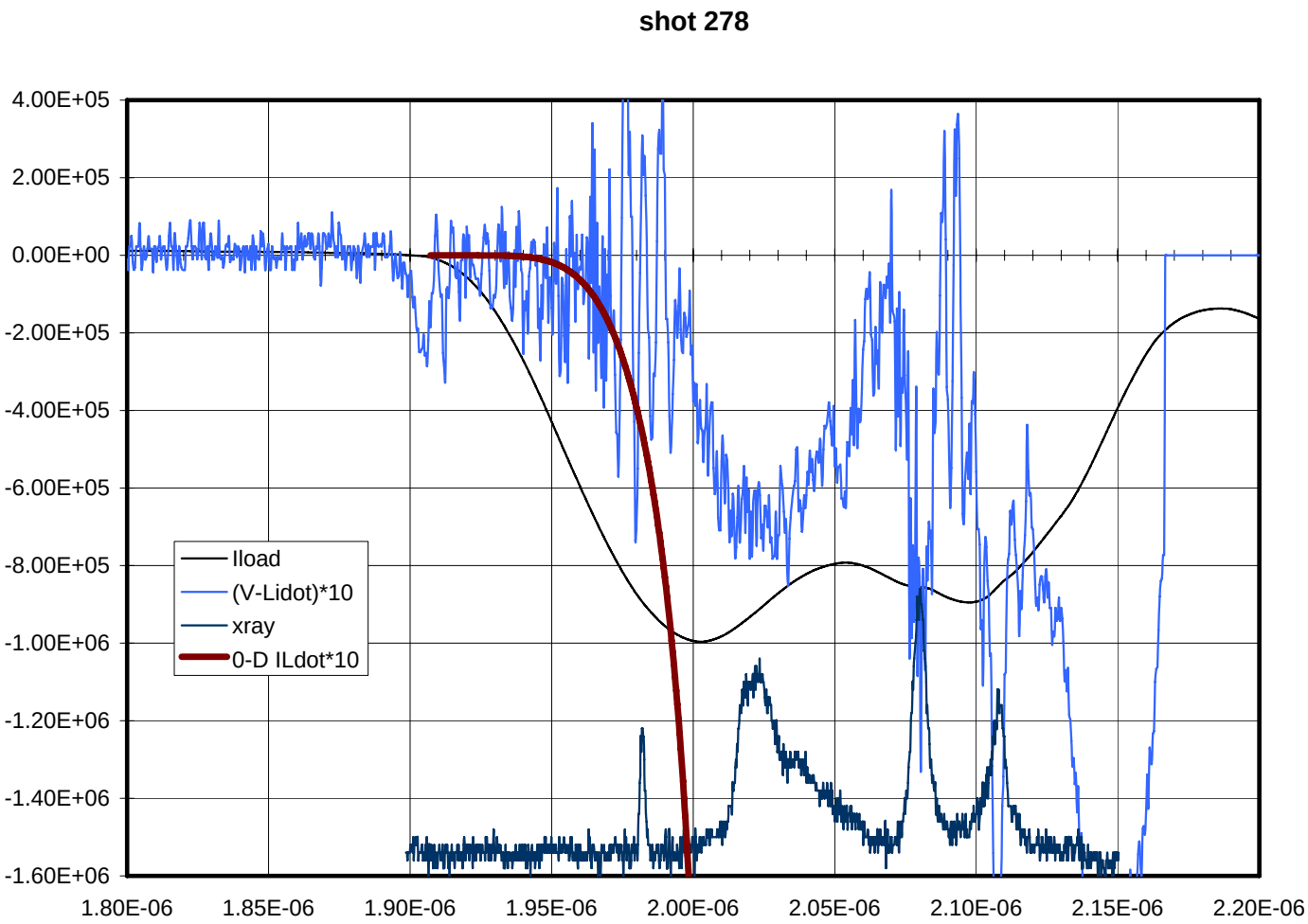


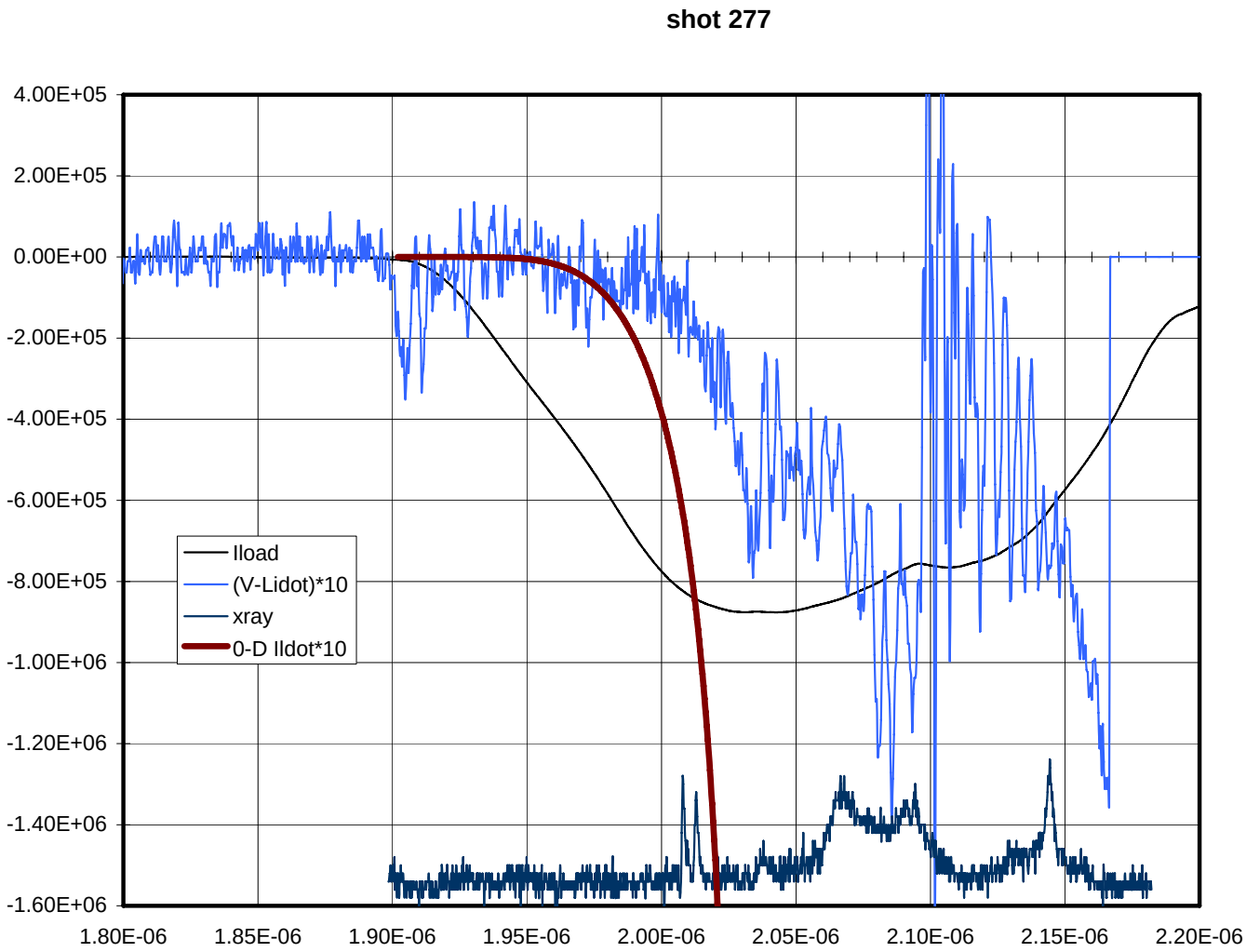

energy integrals 277
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
-2.00E+03
-4.00E+03
1.80E-06
1.85E-06
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
V*I
(V-Lidot)*I
ILoad
Lidot*I

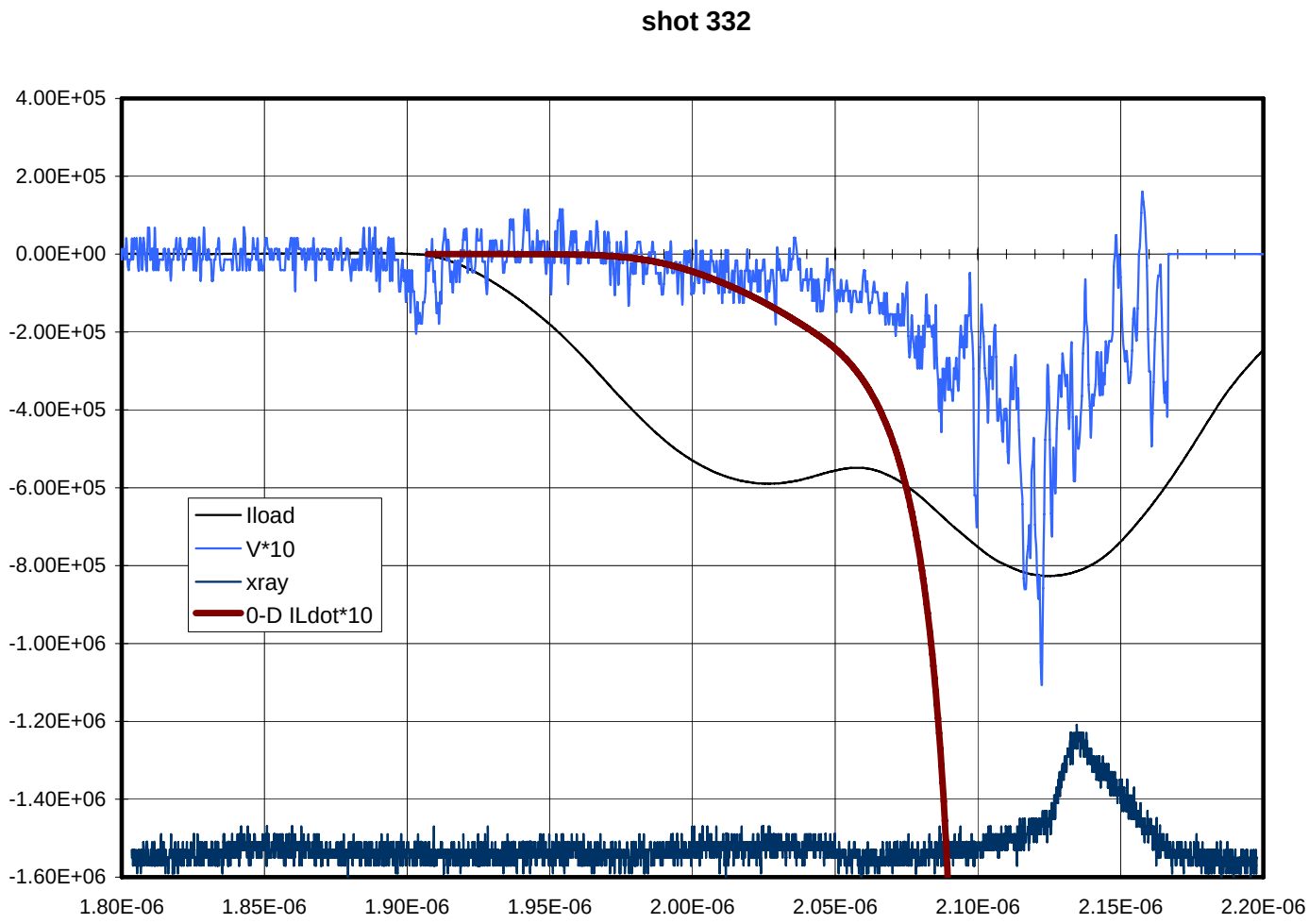
Comparison of (V-Lidot) with O-D calculation of ILdot voltage for a variety of current waveforms:

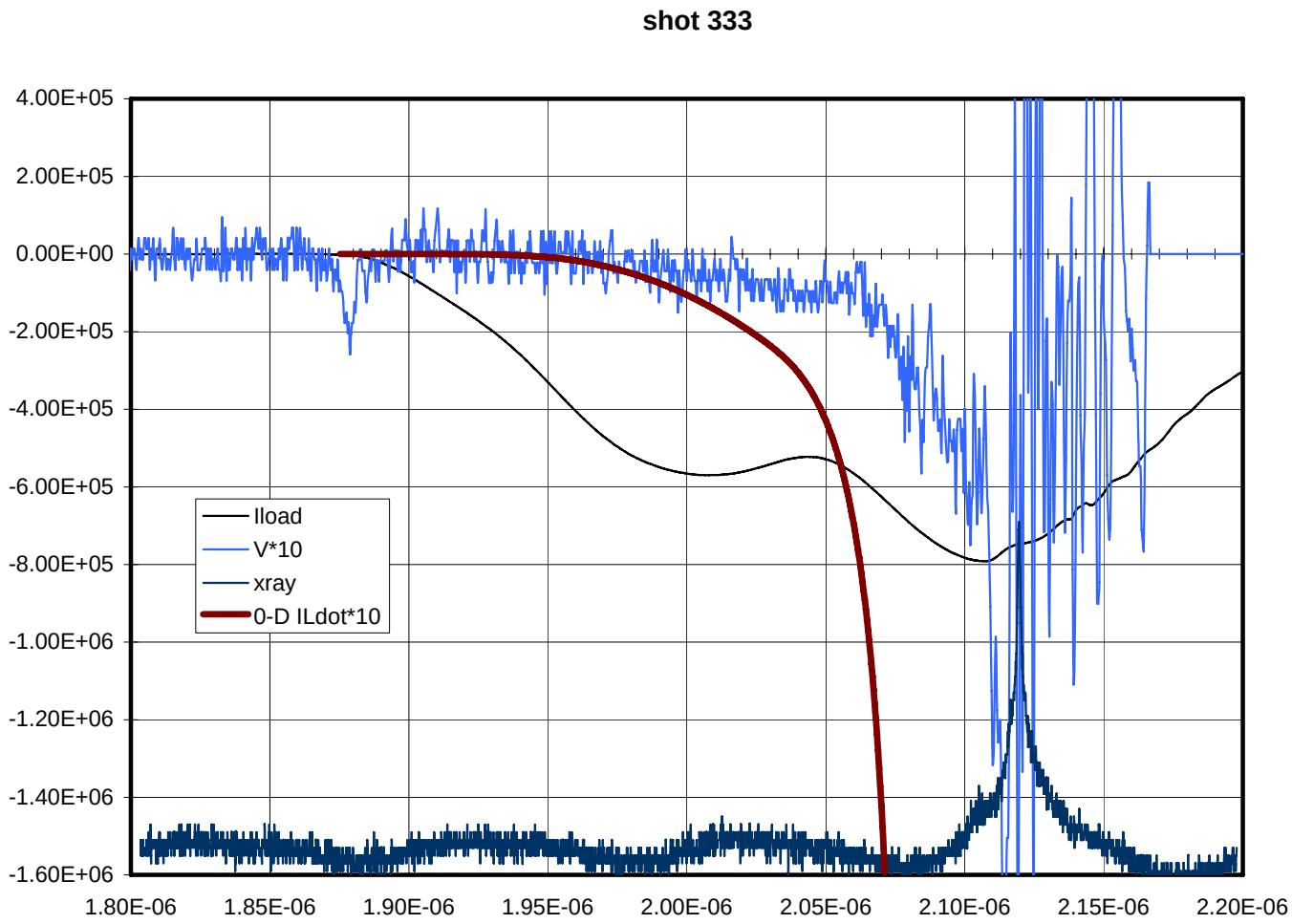
--Experiment always lags O-D voltage

--Experimental voltage stops rising at relatively low value.


shot 278
4.00E+05
2.00E+05
0.00E+00
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
-1.00E+06
-1.20E+06
-1.40E+06
-1.60E+06
1.80E-06
1.85E-06
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
Iload
(V-Lidot)*10
xray
0-D ILdot*10


shot 277
4.00E+05
2.00E+05
0.00E+00
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
-1.00E+06
-1.20E+06
-1.40E+06
-1.60E+06
1.80E-06
1.85E-06
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
Iload
(V-Lidot)*10
xray
0-D Ildot*10


shot 332
4.00E+05
2.00E+05
0.00E+00
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
-1.00E+06
-1.20E+06
-1.40E+06
-1.60E+06
1.80E-06
1.85E-06
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
Iload
V*10
xray
0-D ILdot*10


shot 333
4.00E+05
2.00E+05
0.00E+00
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
-1.00E+06
-1.20E+06
-1.40E+06
-1.60E+06
1.80E-06
1.85E-06
1.90E-06
1.95E-06
2.00E-06
2.05E-06
2.10E-06
2.15E-06
2.20E-06
Iload
V*10
xray
0-D ILdot*10

If you take the experimental (V-LIdot),

--assume it is all ILdot (neglect resistive voltage)

--use the O-D model to get r(t).

then at the first peak of voltage:

Shot	O-D radius	I risetime (0-100)
278	6.2mm	95 ns
277	5.6mm	135 ns
332	3.8mm	210 ns
333	2.8mm	235 ns

--COBRA with laser triggered switching is able to provide a reproducible current pulse with widely variable characteristics of risetime and shape.

--Differences are seen in wire array impedance behavior with different driving pulse shapes.

--Load voltage monitor may help understanding, BUT: need very good modeling to distinguish ILdot from resistance.