Electron-beam Dynamics in the Long-Pulse, High-Current DARHT-II Linear Induction Accelerator

Carl Ekdahl, for the DARHT-II Team

Los Alamos National Laboratory

Presented at

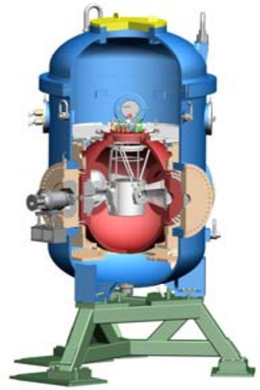
EPAC08

Los Alamos

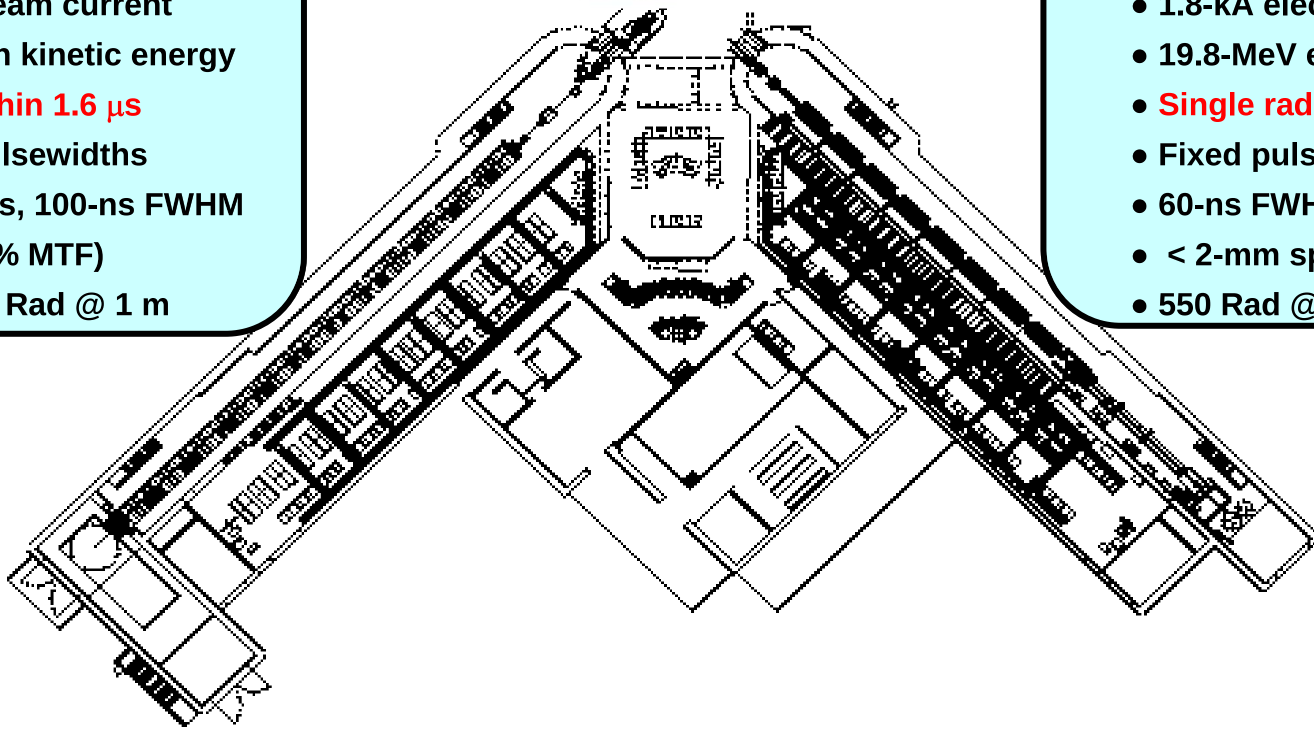
DARHT

Dual-Axis Radiographic Hydrotest Facility.

- Flash radiography of large, high-explosive driven experiments contained in vessels.
- Two accelerators provide simultaneous, orthogonal radiographs.



- Axis 2, Completed 2008
- Linear Induction Accelerator
- 2.0-kA electron-beam current
- > 17-MeV electron kinetic energy
- 4 radiographs within 1.6 μs
- Programmable pulsewidths
- 35-ns, 40-ns, 40-ns, 100-ns FWHM
- < 2 mm spots (50% MTF)
- 170, 185, 170, 445 Rad @ 1 m



- Axis 1, Completed 1999
- Linear Induction Accelerator
- 1.8-kA electron-beam current
- 19.8-MeV electron kinetic energy
- Single radiograph
- Fixed pulsewidth
- 60-ns FWHM
- < 2-mm spot (50% MTF)
- 550 Rad @ 1 m

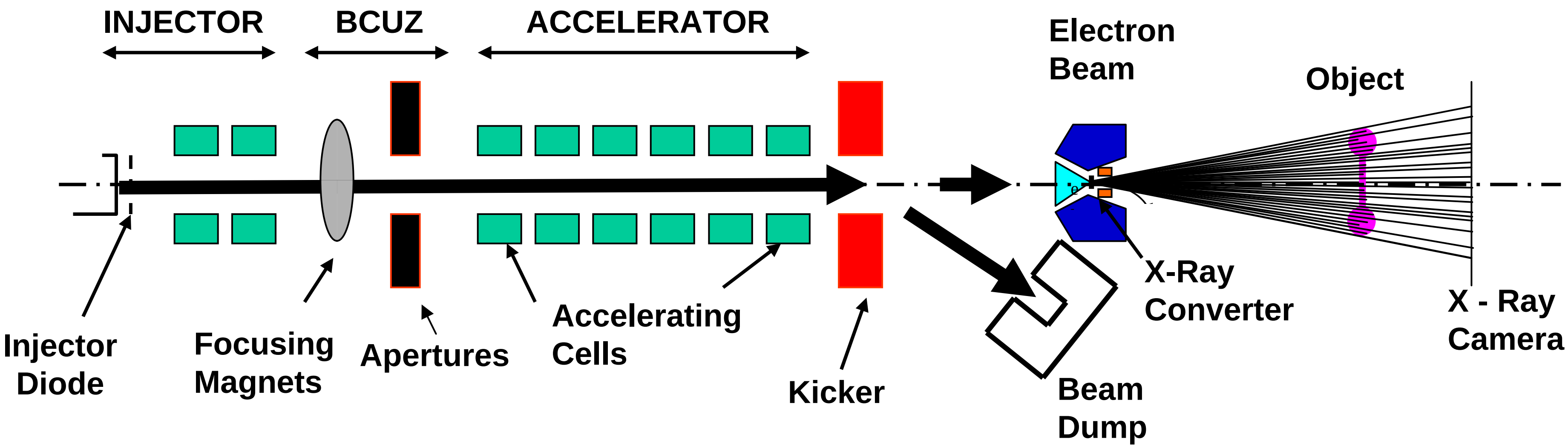
Los Alamos

In this talk I will briefly tell you about:

- Results of commissioning DARHT-II, which has now had all of its cells replaced with an improved design providing 40% higher accelerating potentials.
- Beam Dynamics in the LIA
  - Sweep resulting from mechanical misalignment and energy variation
  - Beam Breakup (BBU)
  - Ion Hose instability
- Transport of kicked pulses to converter target to produce 4 radiography-source spots

DARHT

The multiple-pulse DARHT-II is a significant advance in LIA technology.



- Commissioning completed March 2008
- Injector diode – 2.5 MeV, 2 kA, 1.6 μs
  - Marx generator powered
  - Hot dispenser cathode
- 6 Injector cells at 185 keV/cell
- 68 Accelerator cells at 216 keV/cell

- Final Beam Energy > 17 MeV
- Kicker system used to produce 4 pulses on the x-ray target:
- < 2 mm spot size (50% MTF)
- 35-ns, 40-ns, 40-ns, 100-ns pulse FWHM
- 170, 185, 170, 445 Rad @ 1 m

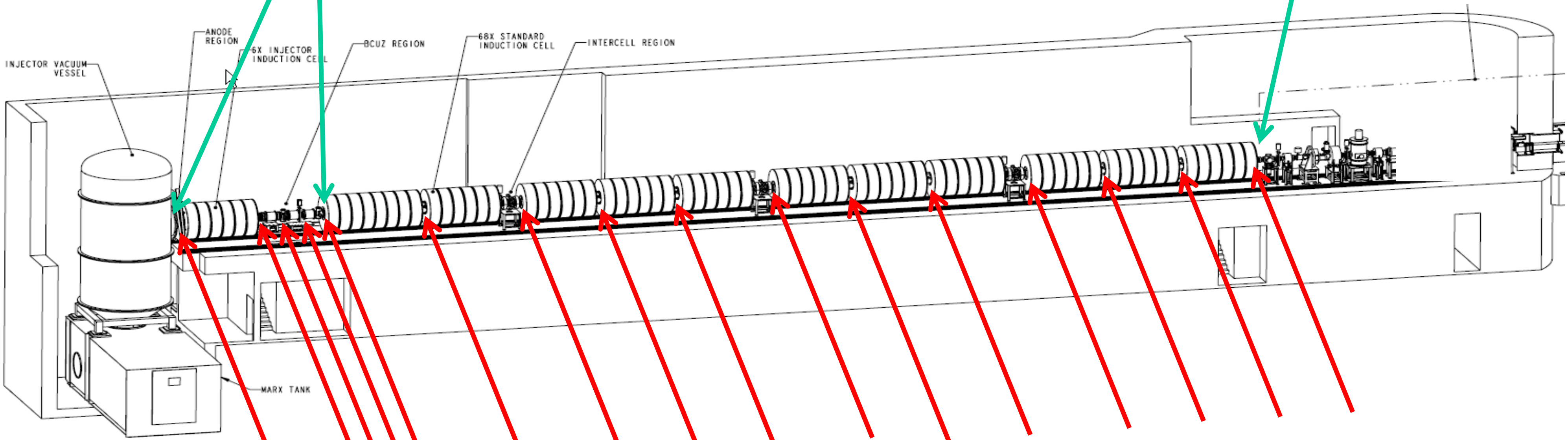
Los Alamos

Beam position monitors (BPM) measure position and current throughout the accelerator.

High-bandwidth recording is used at entrance and exit to measure BBU

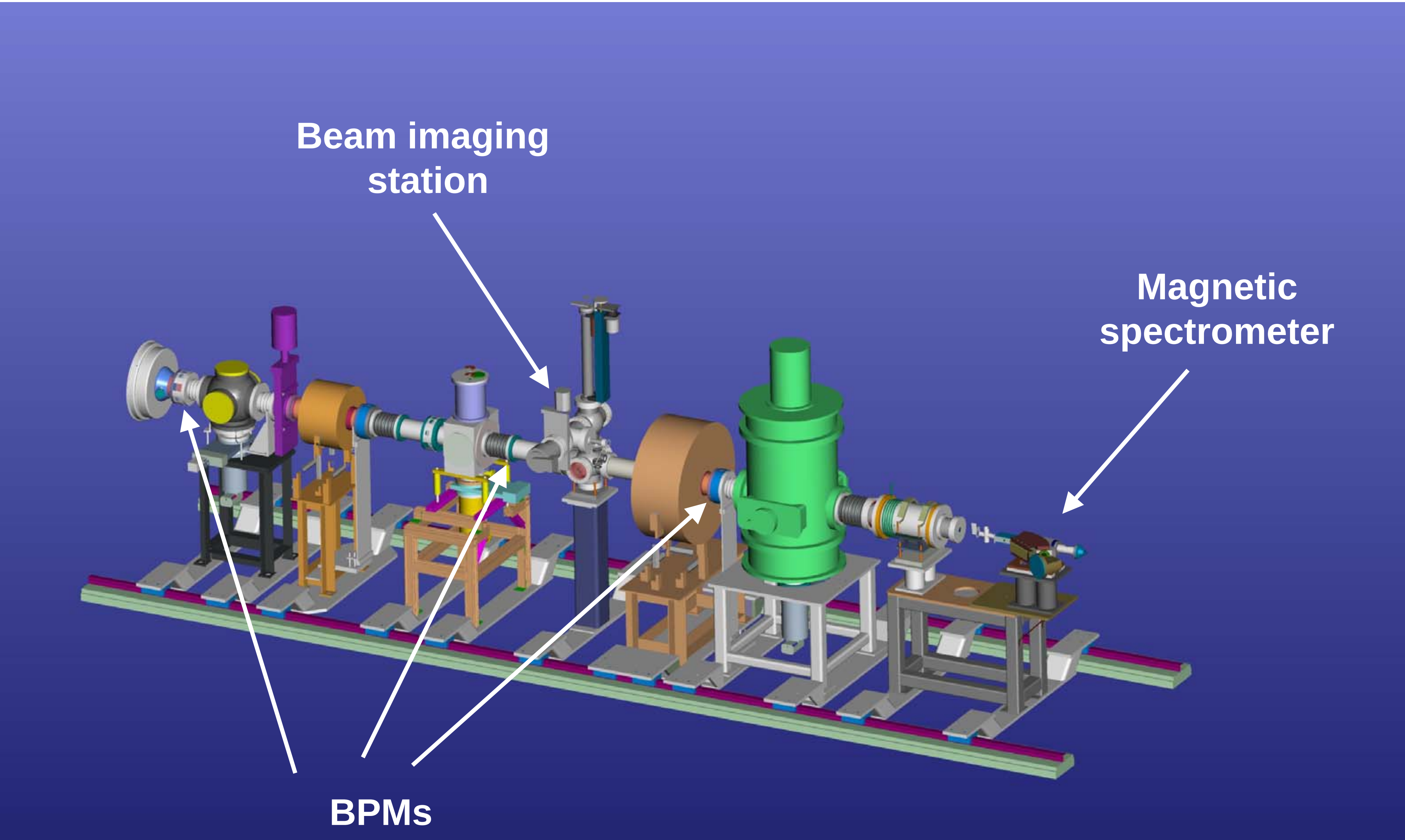
2 Gs/s

5 Gs/s

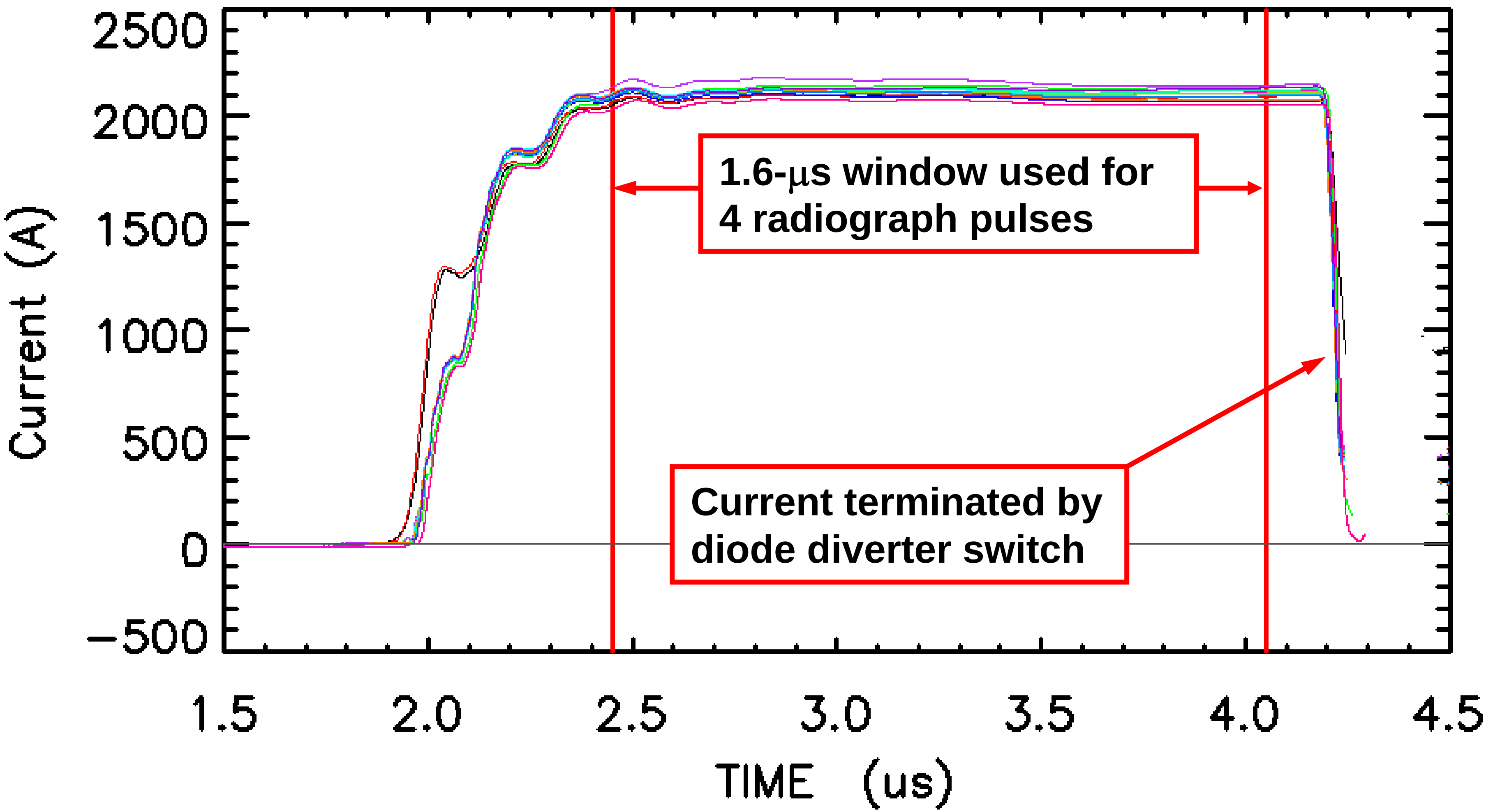


BPMs are located at the diode exit, at the entrance to every block of cells, and at the accelerator exit.

For commissioning, we installed diagnostics after the exit to measure the accelerated beam parameters.

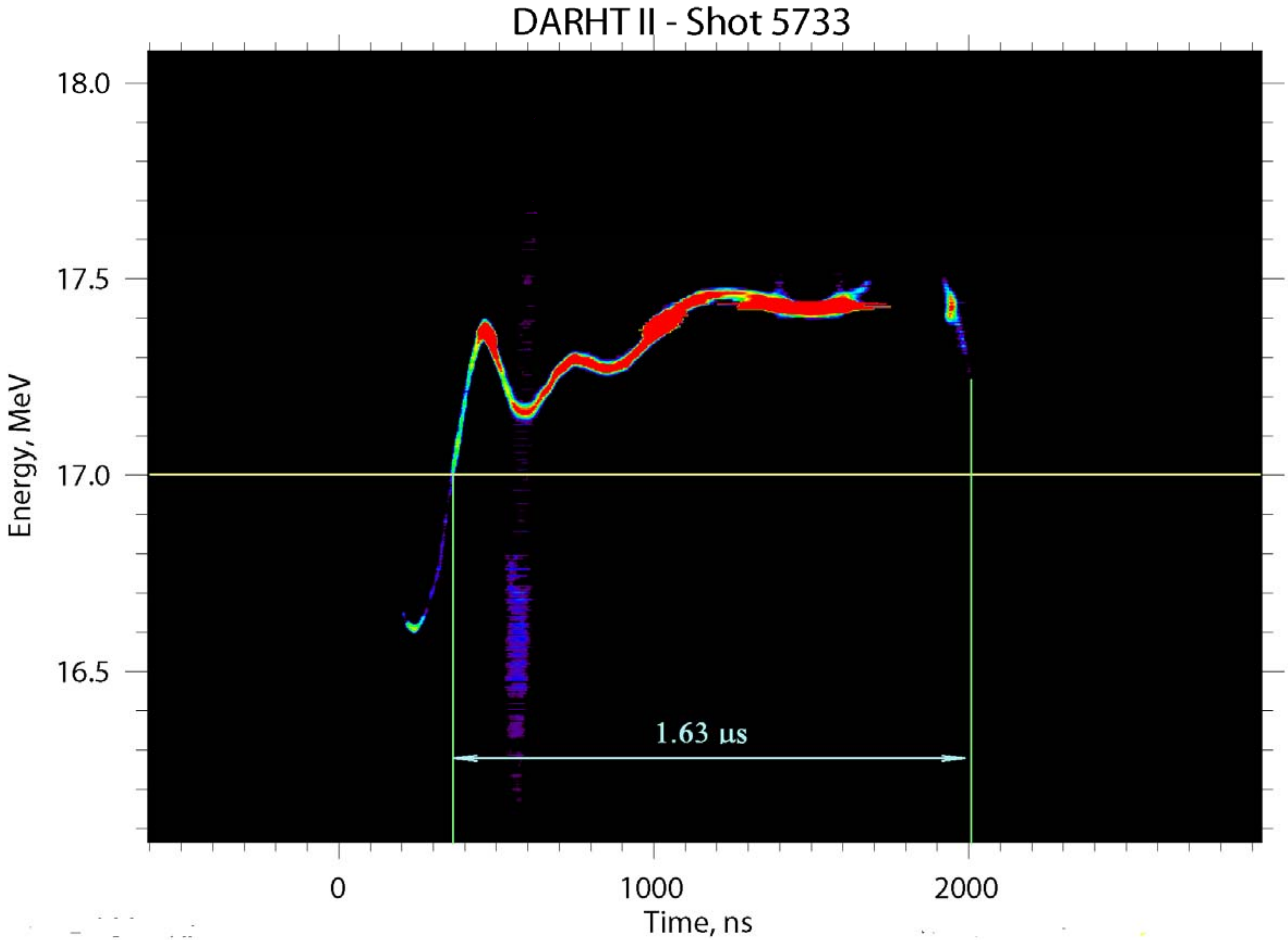


DARHT-II produces a 2-kA electron beam in a pulse with a flat top > 1.6 μs that is transported through the accelerator without losses.

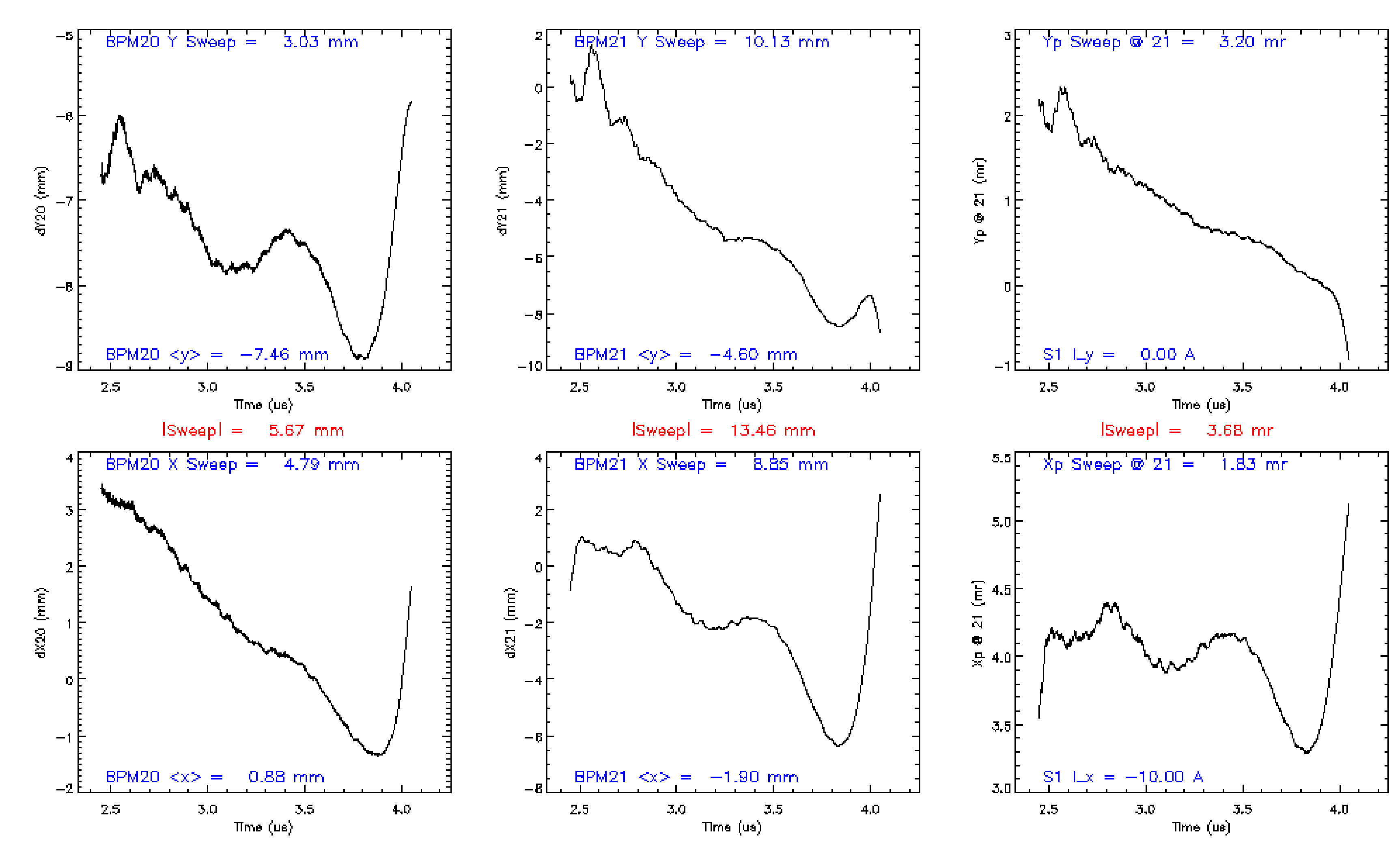


Overlay of BPM Measurements

The DARHT-II accelerated beam kinetic energy exceeds 17 MeV over the 1.6 μs window for multi-pulse radiography.

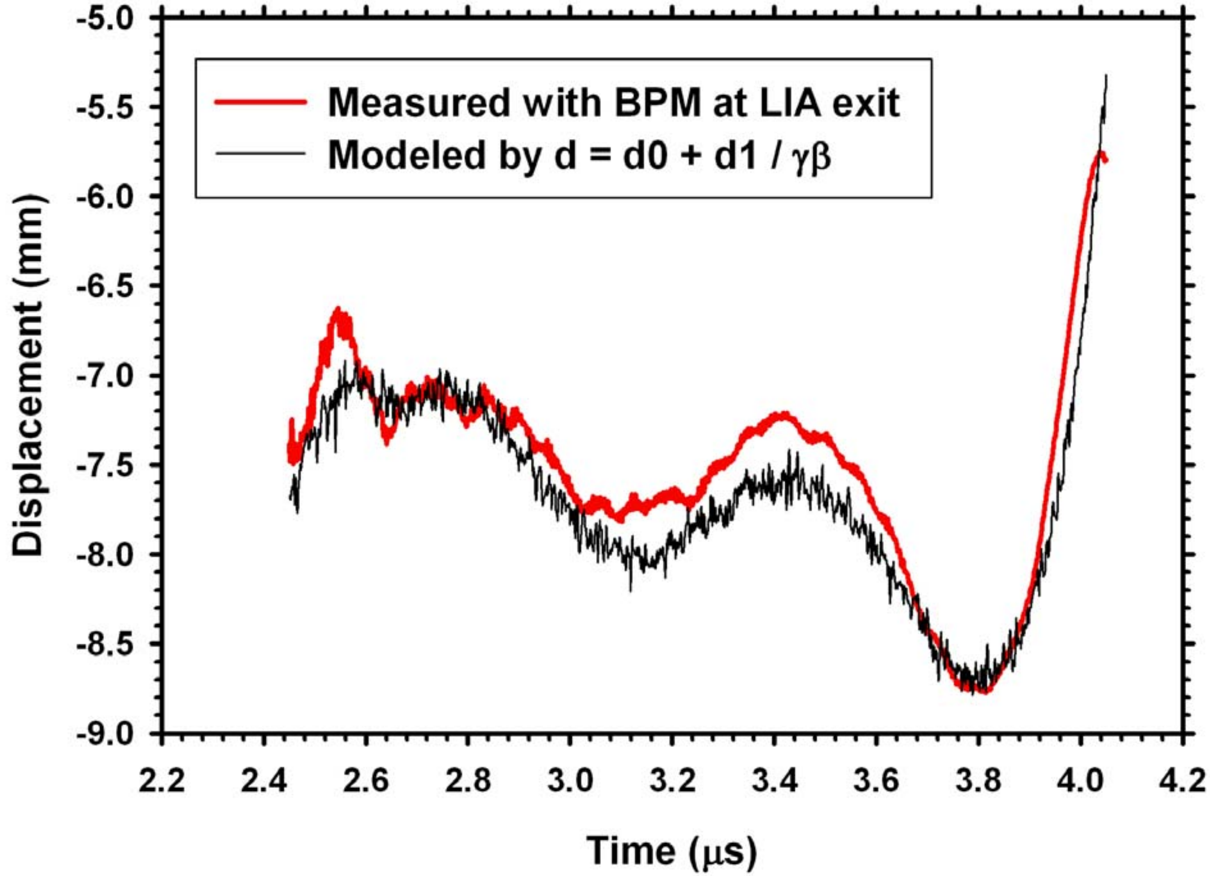


A slow, energy-dependent sweep dominated the beam motion at the LIA exit.



DARHT

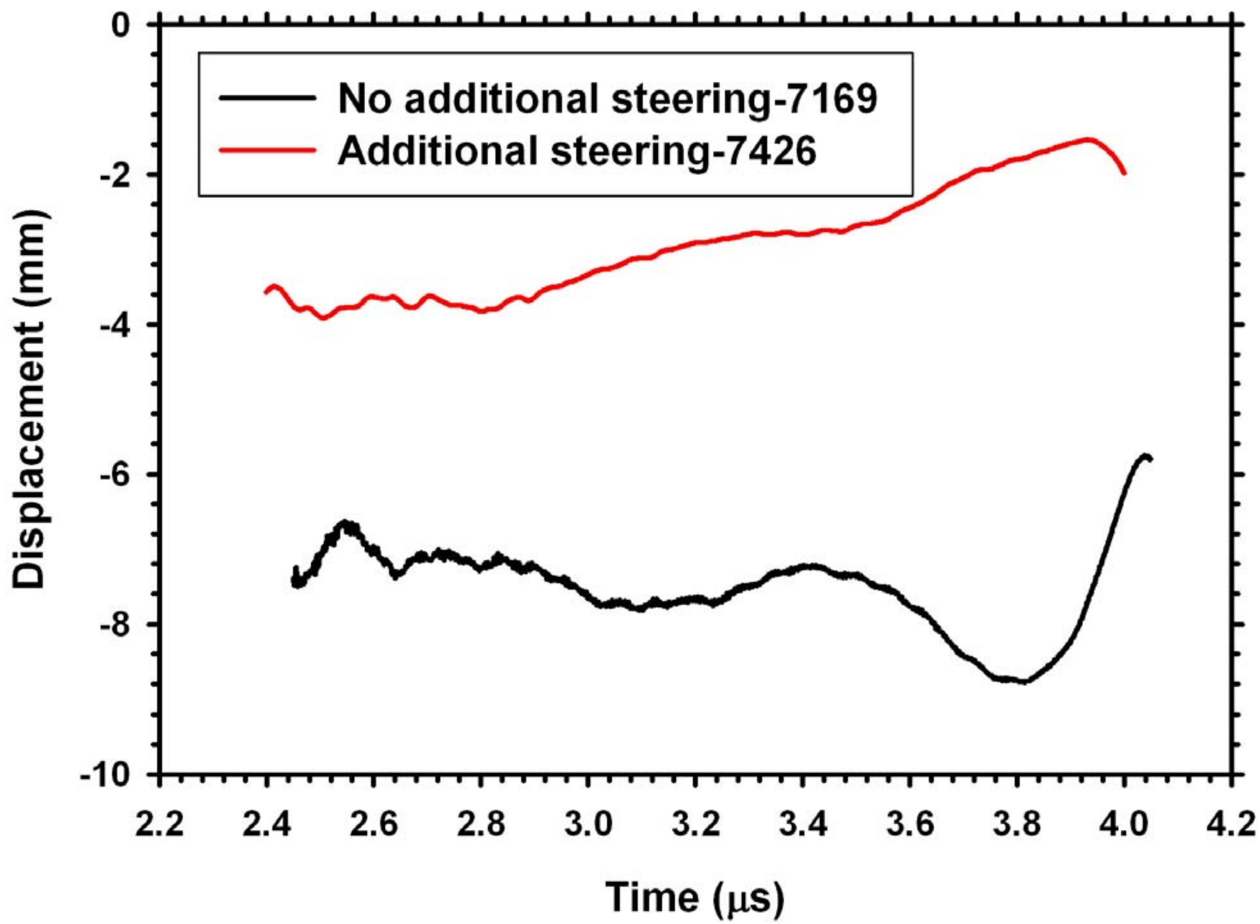
The strong energy dependence suggests that the sweep is an interaction with misalignment produced dipoles, and not the resistive wall instability.



In a solenoidal focusing field, the resistive-wall instability growth is independent of energy

Los Alamos

We demonstrated that we could reduce the sweep energy dependence by using additional dipole steering through the accelerator.



Los Alamos

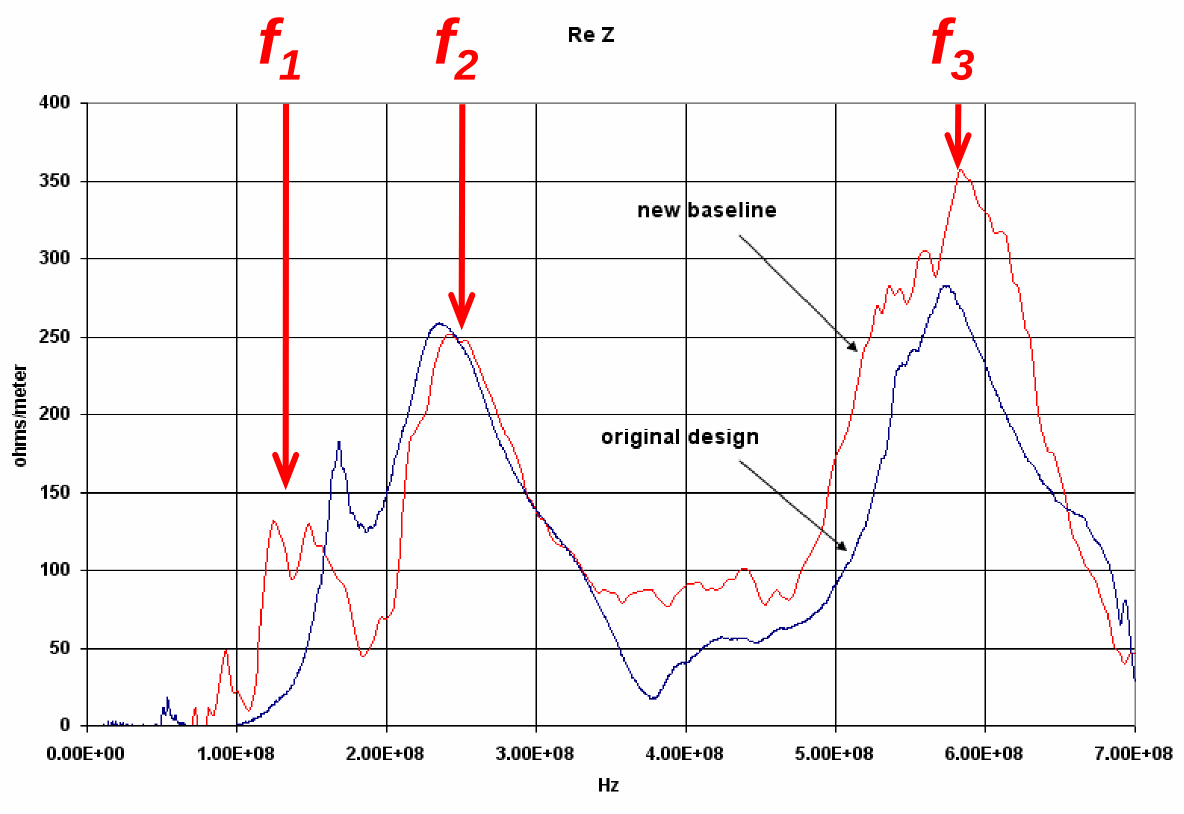
DARHT

The beam-breakup (BBU) instability is problem for high-current linear induction accelerators.

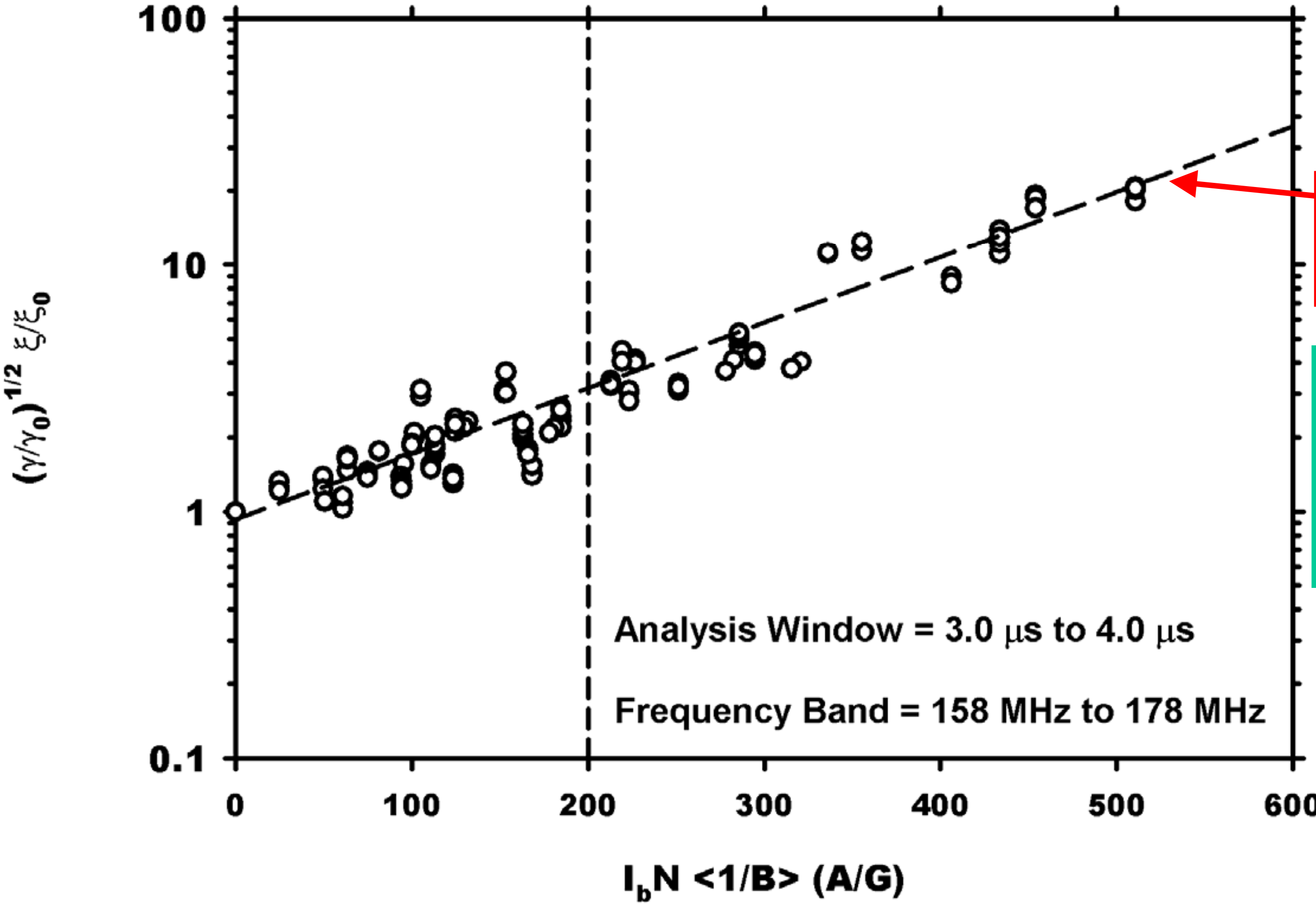
- **In the high-current, strongly-focused, accelerated-beam regime the BBU rapidly grows to a saturated amplitude:**

$$\xi/\xi_0 = (\gamma_0/\gamma)^{1/2} e^{\Gamma} \quad \textbf{with} \quad \Gamma = I_b N_G Z_\perp \langle 1/B_Z \rangle / 3E4$$

- ***The transverse impedance, $Z_\perp$, of individual cells was measured using RF techniques at LBNL in both the original and the new cells.***



In an earlier experiment with the original cells (2005), we confirmed the theoretical scaling of BBU growth.

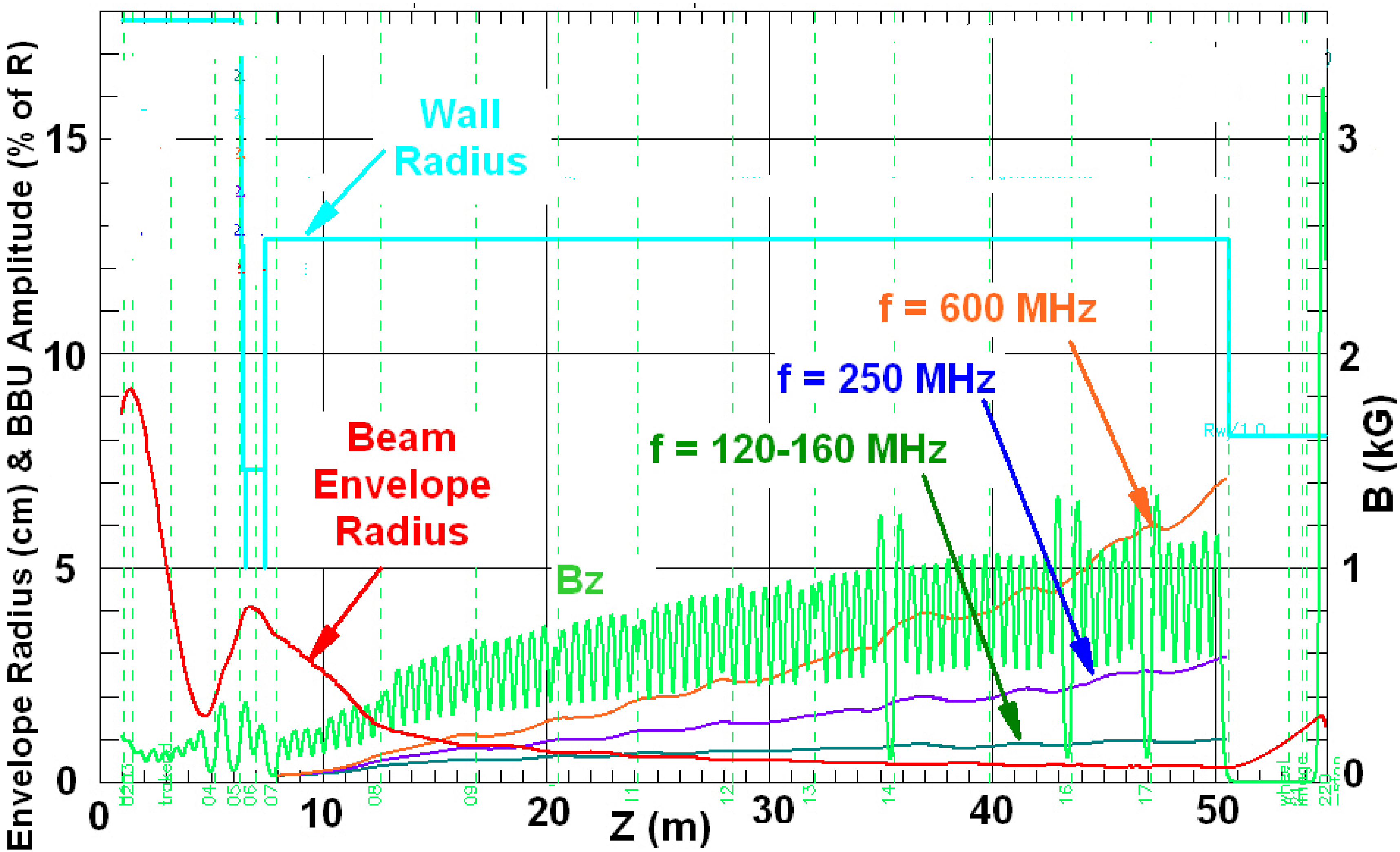


Best Fit to data is with $Z_\perp$ = 184 ± 6 Ω/m

Direct RF measurement of $Z_\perp$ in a cell : 157 Ω/m average over 158 – 178 MHz band

Carl Ekdahl, et al., *IEEE Trans. Plasma. Sci. Vol. 34*, 2006, pp. 460-466

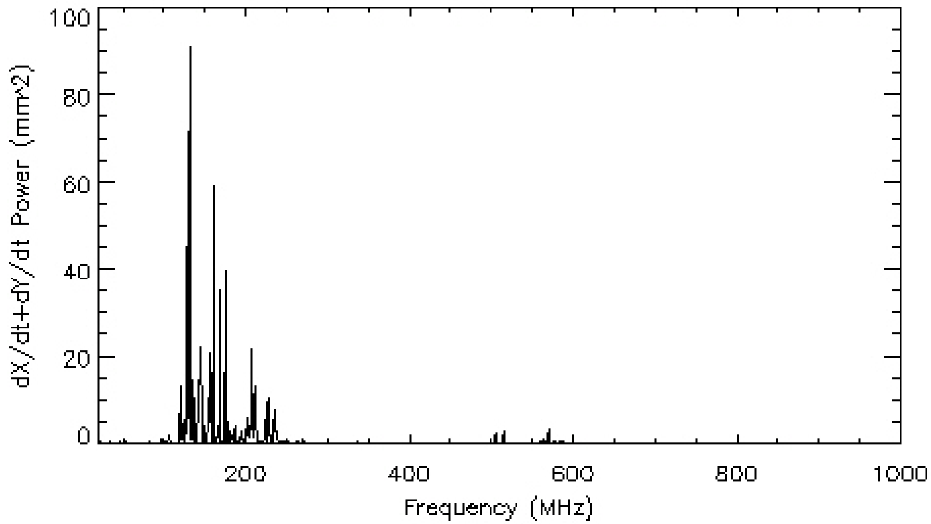
We use a solenoidal magnetic focusing tune strong enough to suppress the beam-breakup (BBU) instability to less than 10% of the beam radius.

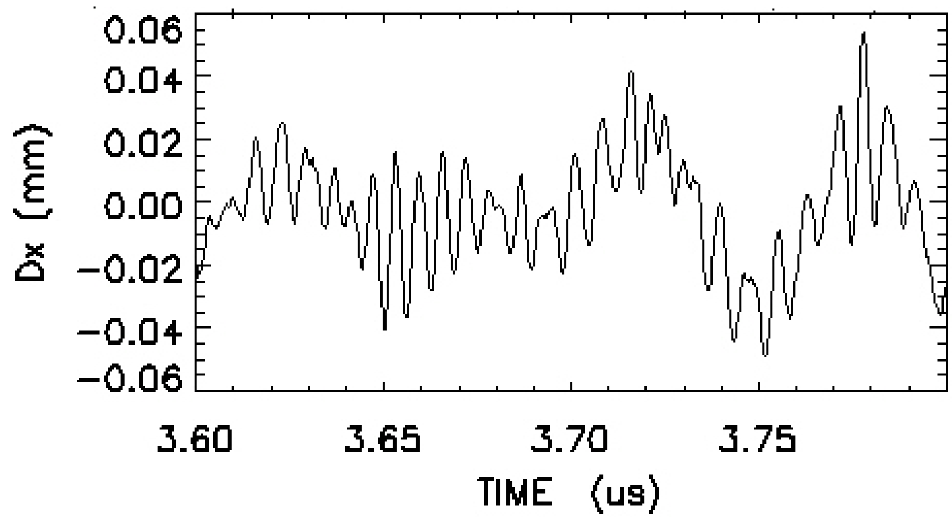


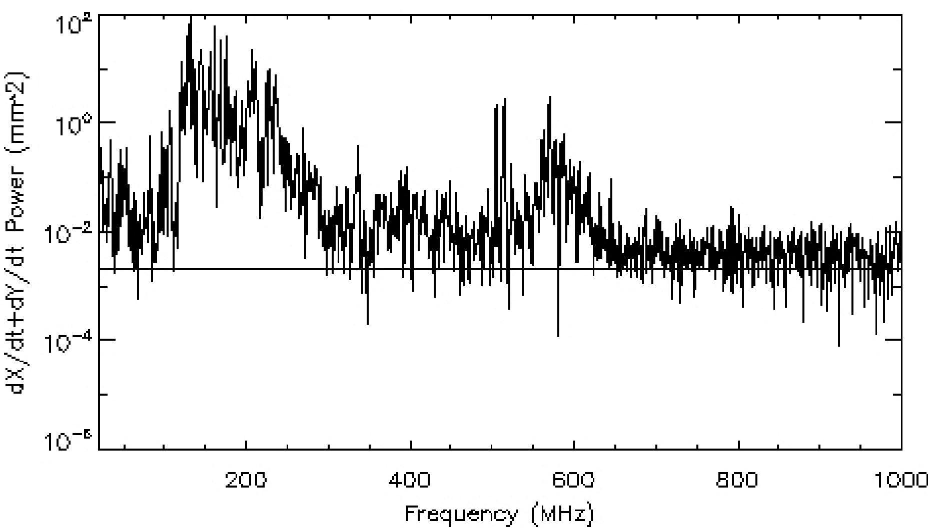
Los Alamos

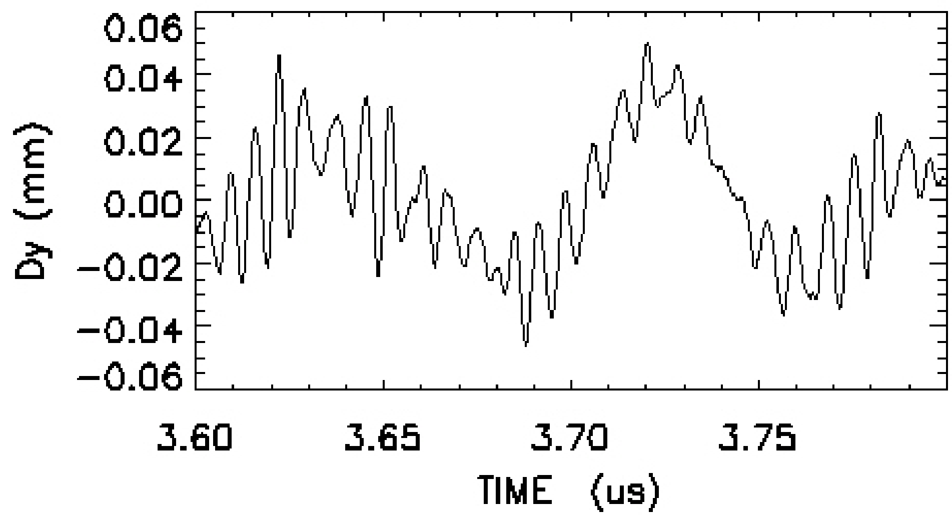
DARHT

We observe BBU in all of the resonant bands of the cells. The 60-micron amplitude is much smaller than the beam size and acceptable for our present application.









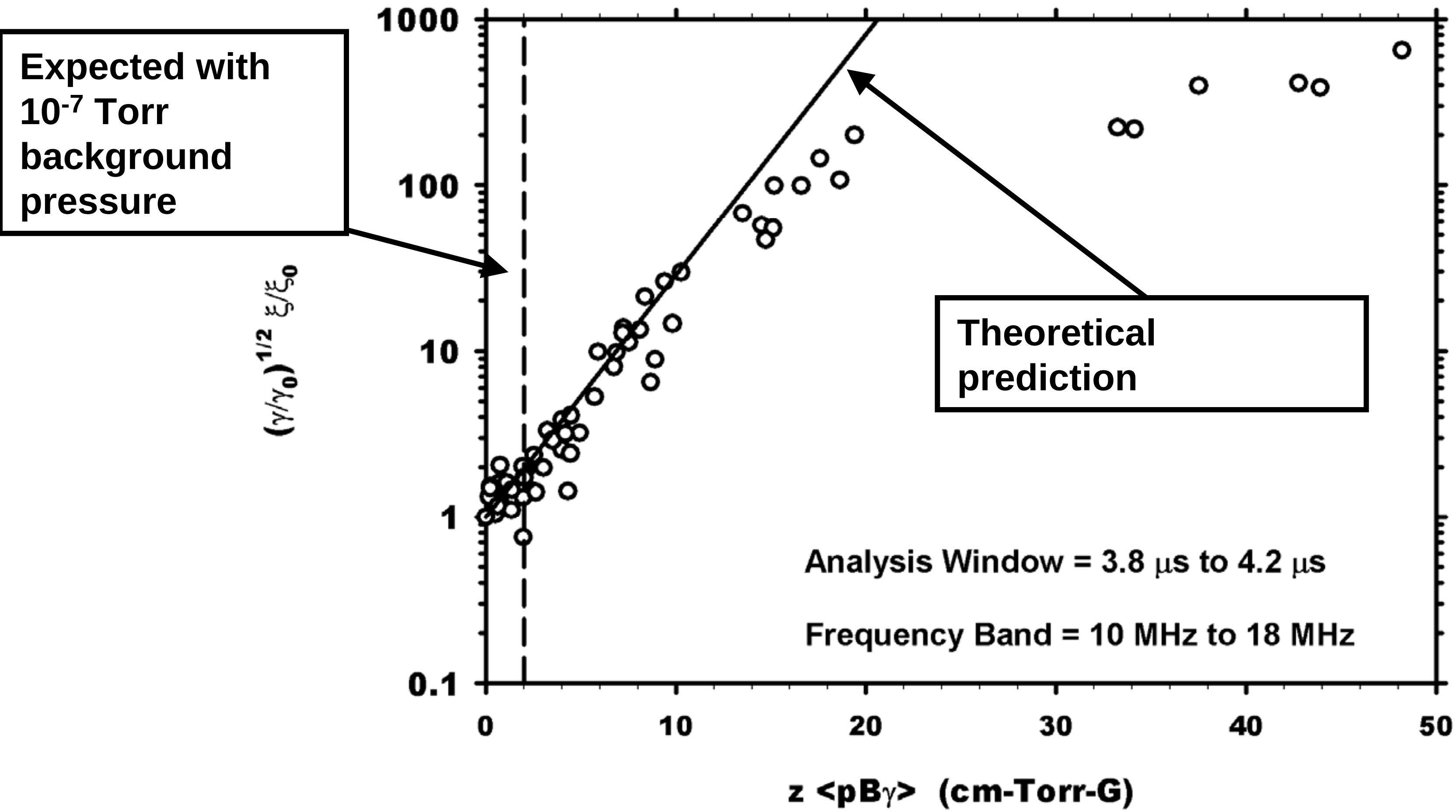
We observe occasional low-frequency motion that we attribute to interaction with gas liberated in the beam-head cleanup zone (BCUZ).

- The Ion-hose instability is caused by the interaction of the beam with a channel of ionized gas.

- Maximum Growth Factor; $\Gamma \sim I_b \;\tau_{pulse}\, L <p/(Ba^2)>$
  - (Growth saturates just like the BBU)

- Because of the strong dependence on τ_{pulse} this is only a problem for long-pulse beams like DARHT-II
- We take precautions to maintain a hard vacuum to suppress the ion-hose.
- *However, gas liberated by beam scraping on apertures like those in the BCUZ can promote ion hose.*

In an our earlier (2005) stability experiments we confirmed the theoretical scaling of ion-hose growth. We observed an un-predicted further saturation at high magnetic focusing fields.

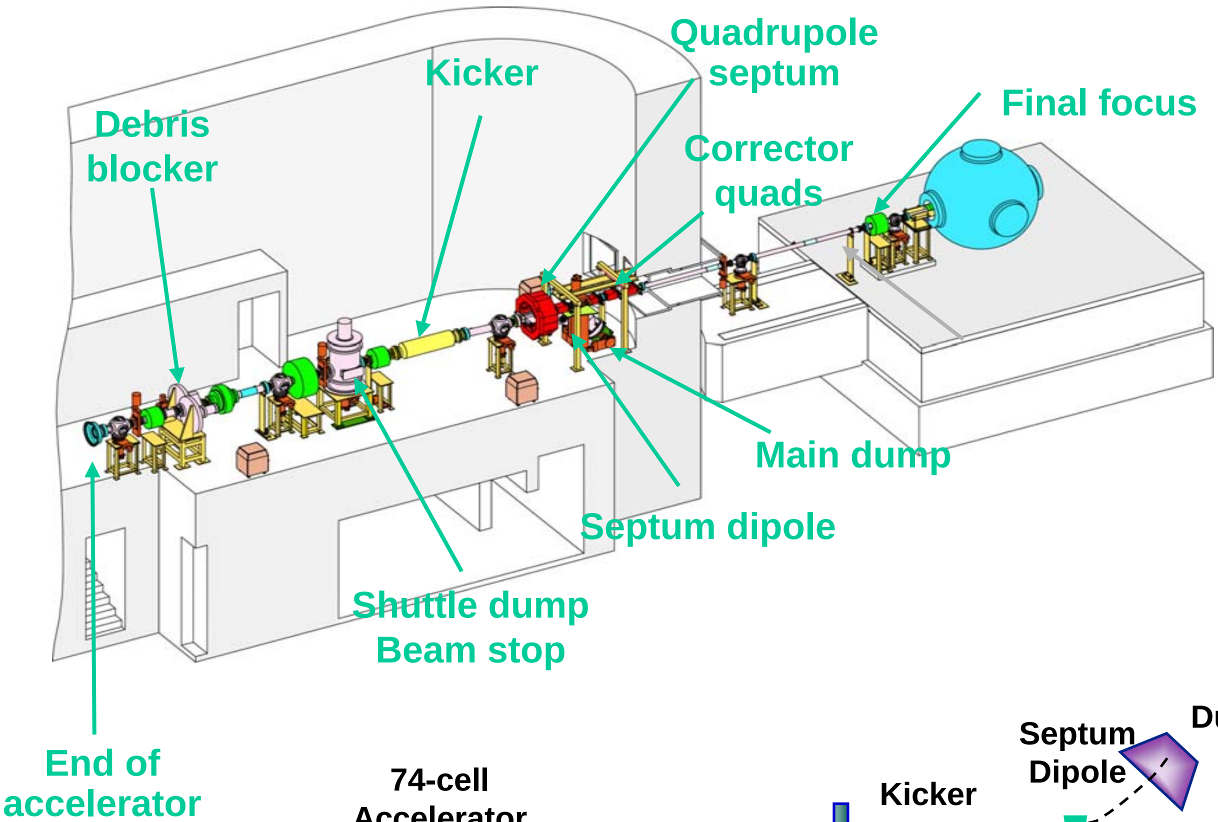


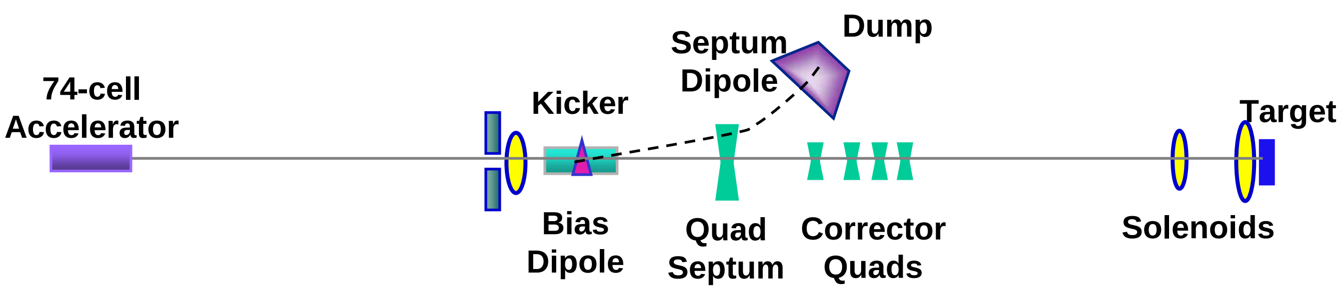
Carl Ekdahl, et al., *IEEE Trans. Plasma. Sci. Vol. 34*, 2006, pp. 460-466

Los Alamos

DARHT

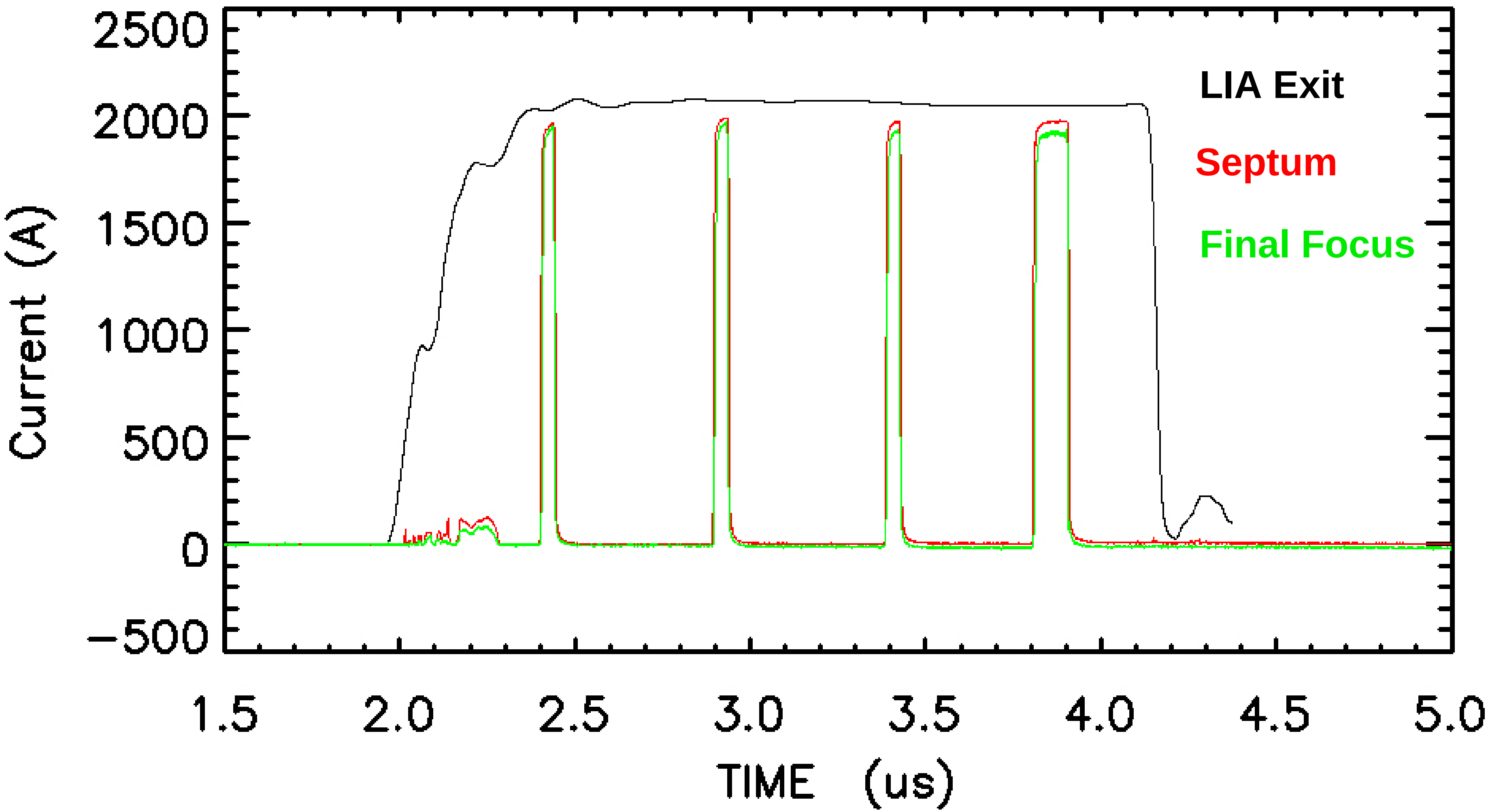
After completing accelerator commissioning, we then installed and commissioned the kicker, downstream transport, and multiple pulse target.





Los Alamos

95% of the kicked-pulse current was transported to the final focus to form the 4 radiography-source spots



Los Alamos

Summary

- **Early this year, DARHT-II was commissioned at its full design energy (17 MeV), current (2 kA), and flat-top pulselength (1.6 μs).**

- **Beam motion from several sources is understood, acceptable, and can be further reduced**
  - **Sweep can be significantly reduced by additional steering through the LIA**
  - **Ion hose can be reduced by reduction of beam scrape in the BCUZ**
  - **BBU is acceptable, although it could be reduced if need be by increasing the magnetic focusing field**

- **Four kicked pulses were successfully transported to the final focus providing good radiography spots.**

The Team that executed these experiments included :

E. O. Abeyta, P. Aragon, R. Archuleta, G. Cook, D. Dalmas,
Carl Ekdahl, K. Esquibel, R. Gallegos, R. Garnett, J. Harrison,
J. Johnson, E. Jacquez, B. Trent McCuistian, N. Montoya, S. Nath,
K. Nielsen, D. Oro, L. Rowton, M. Sanchez, R. Scarpetti,
M. Schauer, G. Seitz, V. Smith, and R. Temple
Los Alamos National Laboratory, Los Alamos, NM 87545, USA

H. Bender, W. Broste, C. Carlson, D. Frayer, D. Johnson,
C. Y. Tom, C. Trainham, and J. Williams,
NSTec, Los Alamos, NM 87544, USA

B. Prichard and M. Schulze,
SAIC, San Diego, CA 92121, USA

T. Genoni, T. Hughes, and C. Thoma,
Voss Scientific, Albuquerque, NM 87108, USA