Amplitude Control of Solid-state Modulators for Precision Fast Kicker Applications

J.A. Watson

R. M. Anaya, G. C. Caporaso, Y.J. Chen, E.G. Cook, B.S. Lee, S.A. Hawkins

Lawrence Livermore National Laboratory

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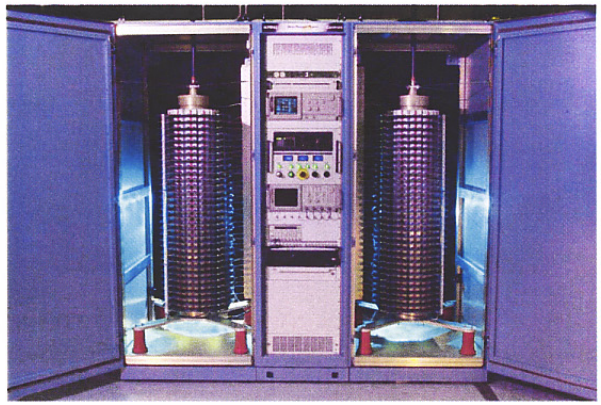
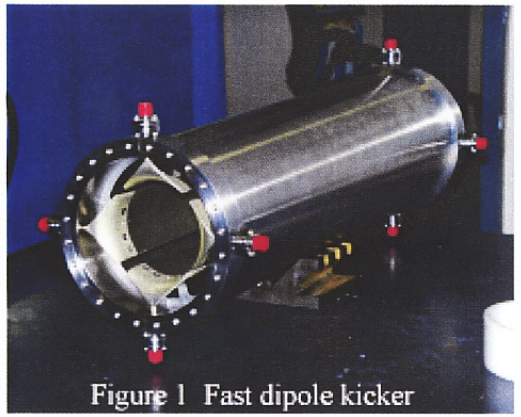
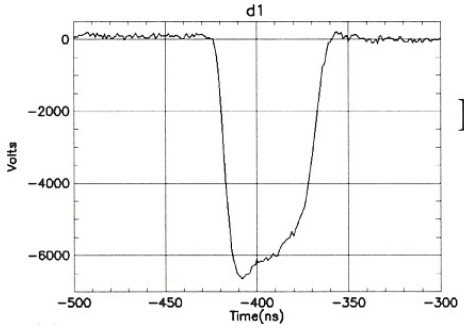
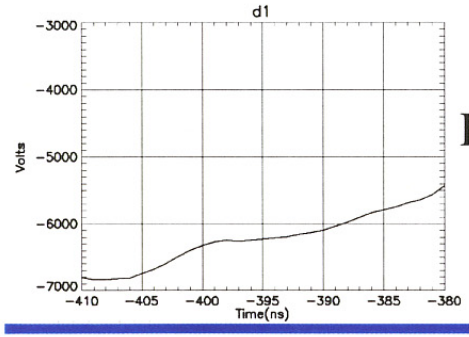
Amplitude Modulation of Kicker Pulsers





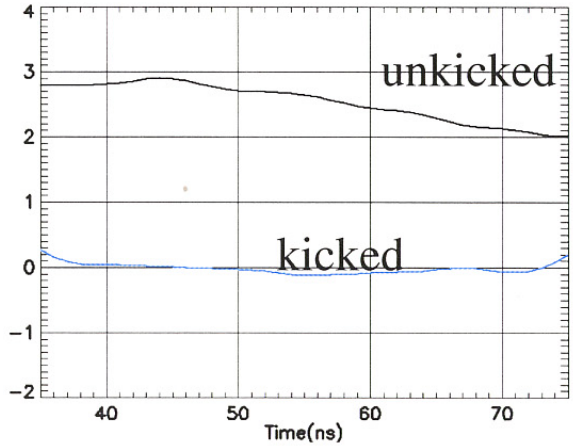


Pulser voltage

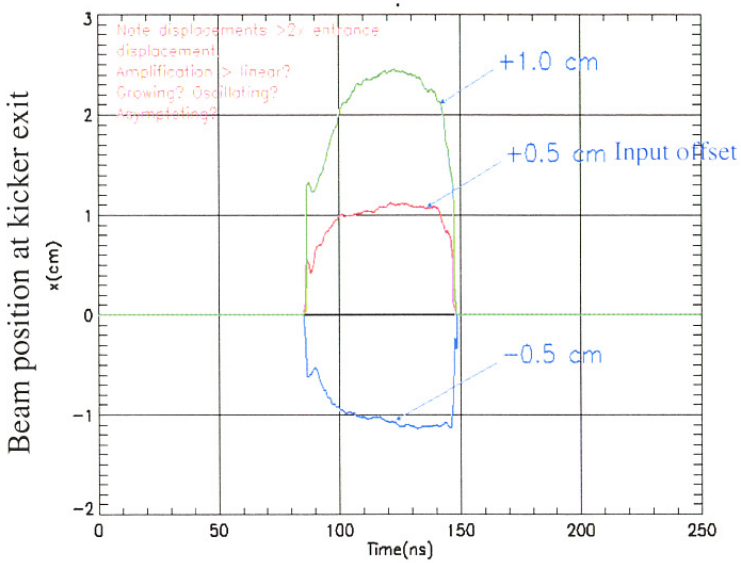


Pulser voltage
(zoomed)

Beam position, cm

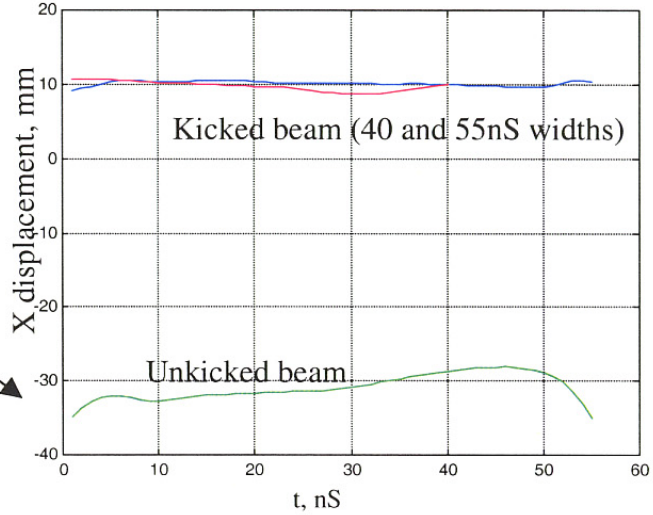


Motivation for Amplitude Modulation of Kicker Pulsers

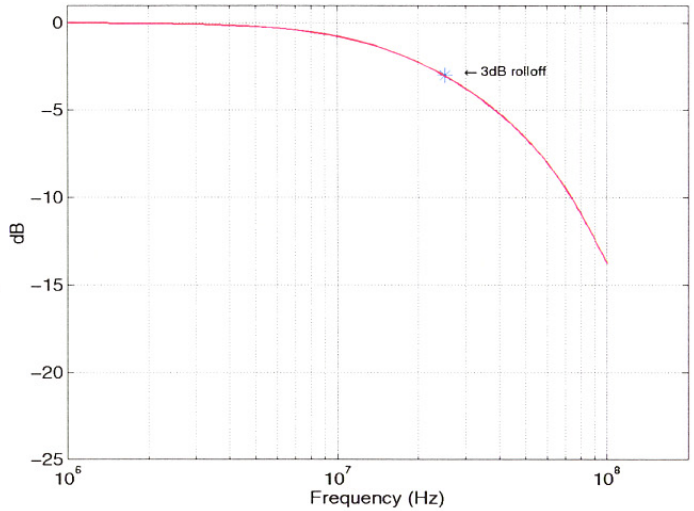


Beam-induced steering in the kicker

Transverse motion in the incoming beam

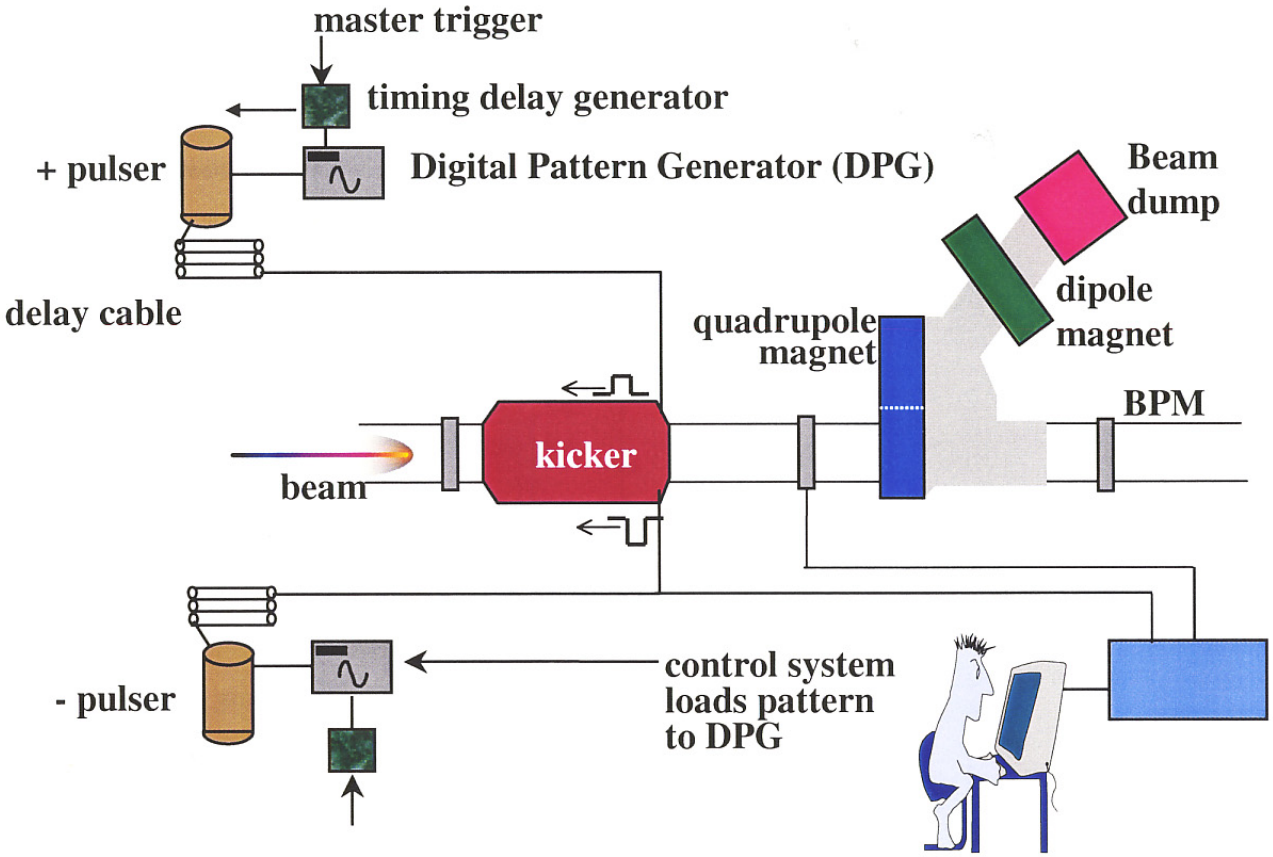


Frequency response of the kicker

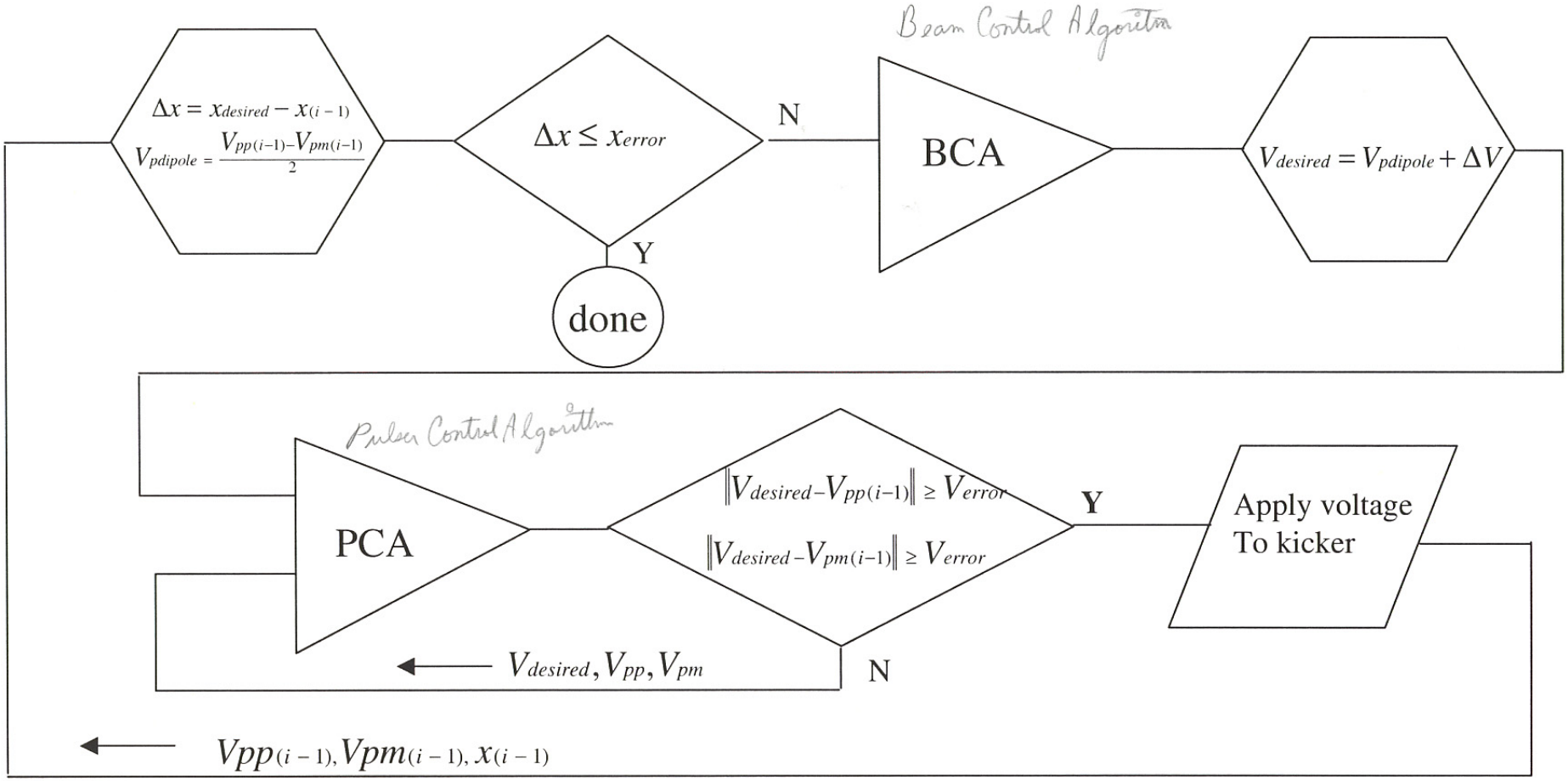


Beam Research Program

Main System Components

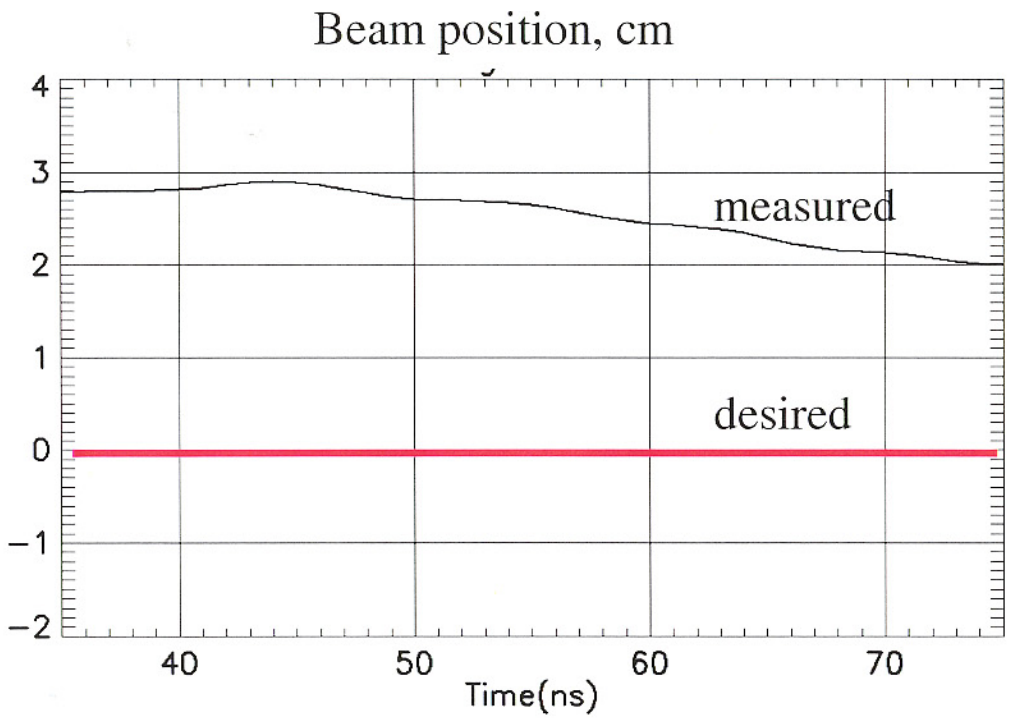


Kicker Control System



Beam Control Algorithm

•Calculates a desired waveform to be applied to the kicker based on measured beam position and an operator-supplied setpoint



Beam Control Algorithm

Deflection of the beam through the kicker (assuming no self-induced effects) is expressed as:

$$x(t) = x_0(t-\frac{l}{c}) + x_0'(t-\frac{l}{c})l + \frac{c^2}{4V_0 l}\int_{t-\frac{2l}{c}}^{t} V_p(t')(t-t'+\frac{2d}{c})dt' + \frac{qB_y l}{\gamma\beta mc}\left(\frac{l}{2}+d\right) \quad (1)$$

Beam Control Algorithm

The correction in deflection due to time-varying pulser waveform at the i-th iteration is:

$$\begin{aligned}\Delta x(t) &= x_{desired} - x^{i-1}(t) \\ &= \frac{c^2}{4V_0 l}\int_{t-\frac{2l}{c}}^{t} \Delta V_p(t')(t - t' + \frac{2d}{c})dt' \qquad (2)\end{aligned}$$

$\Delta x(t)$ and $\Delta Vp(t)$ can be expressed as polynomial series:

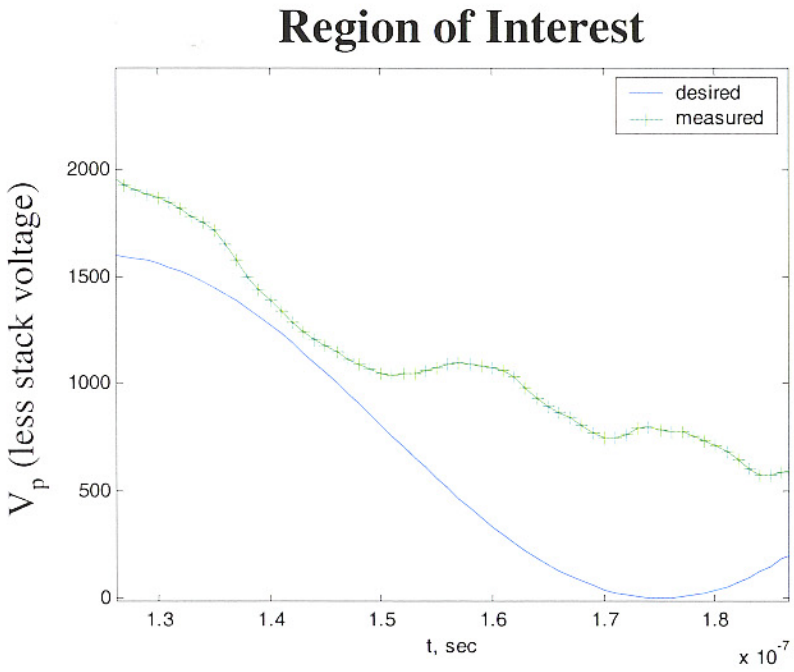
$$\Delta x(l,t) = \sum_{n=0}^{N} \Delta x_n t^n \qquad (3)$$

$$\Delta V_p(t) = \sum_{n=0}^{N} \Delta V_n t^n \qquad (4)$$

By plugging this back into eqn. (2) and collecting like terms, we derive a one-one relationship between Δx_n and $V(n)$. An order N=8 provided more than sufficient fidelity to correct for variation in beam motion on ETA-II.

Pulser Control Algorithm

- Compares measured output of pulsers with desired waveform from Beam Control Algorithm
- Adjusts control to pulsers to match desired waveform
- Sampled data control system
  - T_s = 1nS
  - Control algorithm is applied at every sample point in the region(s) of interest



Pulser Control Algorithm – Adaptive Control

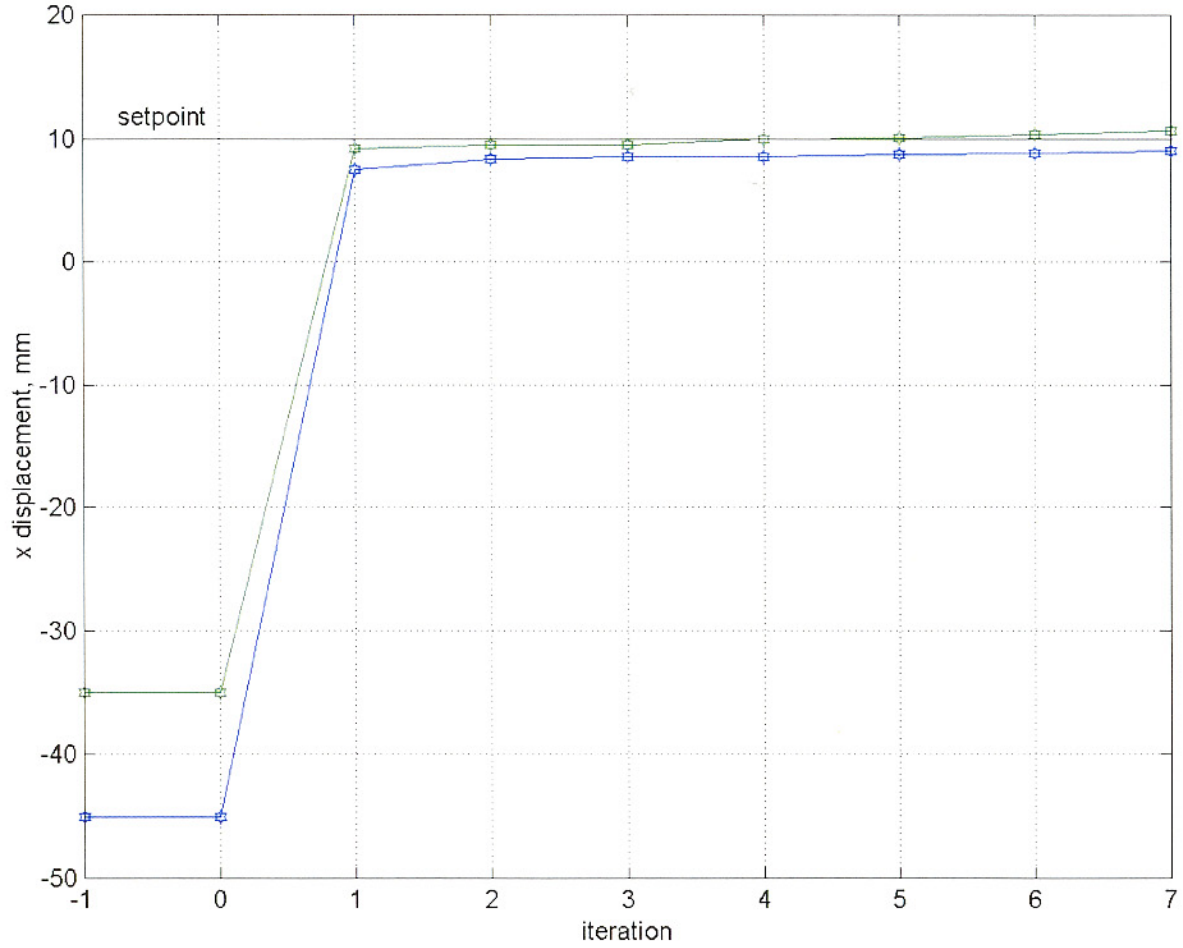
The parameter estimator is given by:

$$\hat{\theta}(k) = \hat{\theta}(k-1) + \frac{\beta\, y(k)y(k-1)}{c + y(k-1)^2}$$ (gradient projection algorithm)

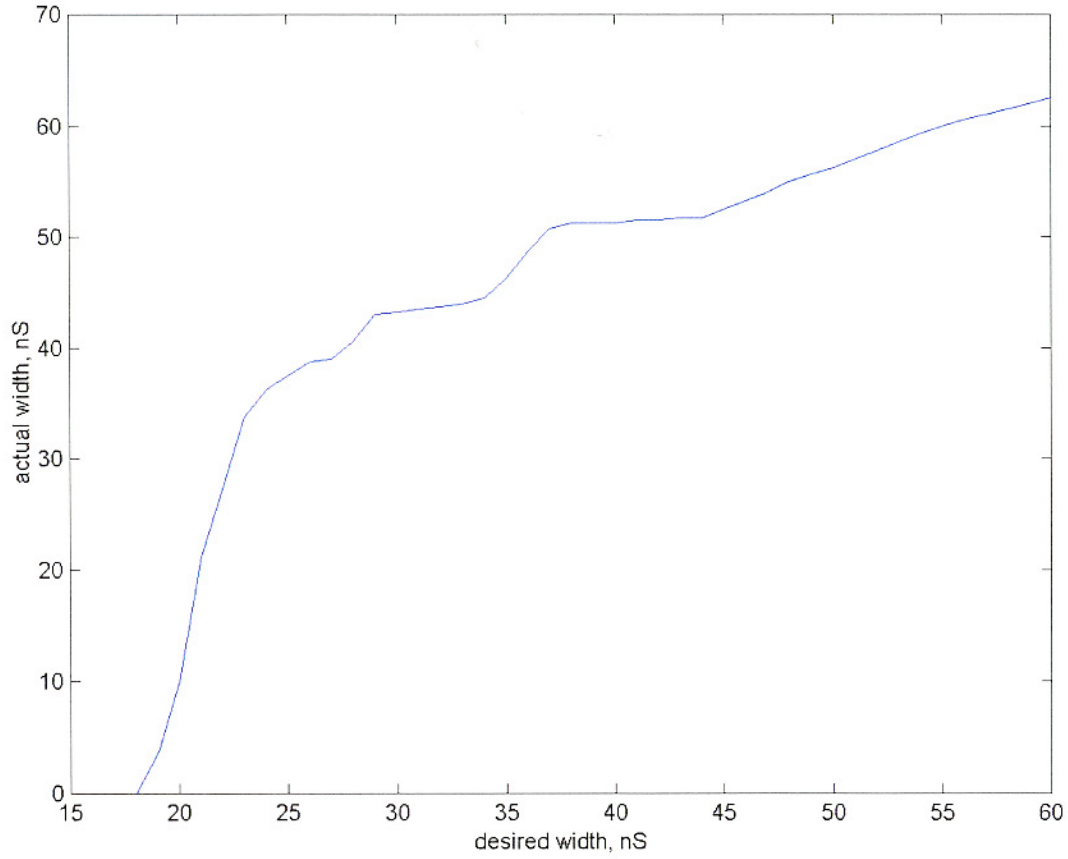
with the control law implemented as:

$$u(k) = u(k-1) + (\hat{\theta}(k) - \alpha)y(k)$$

Control Algorithm Convergence

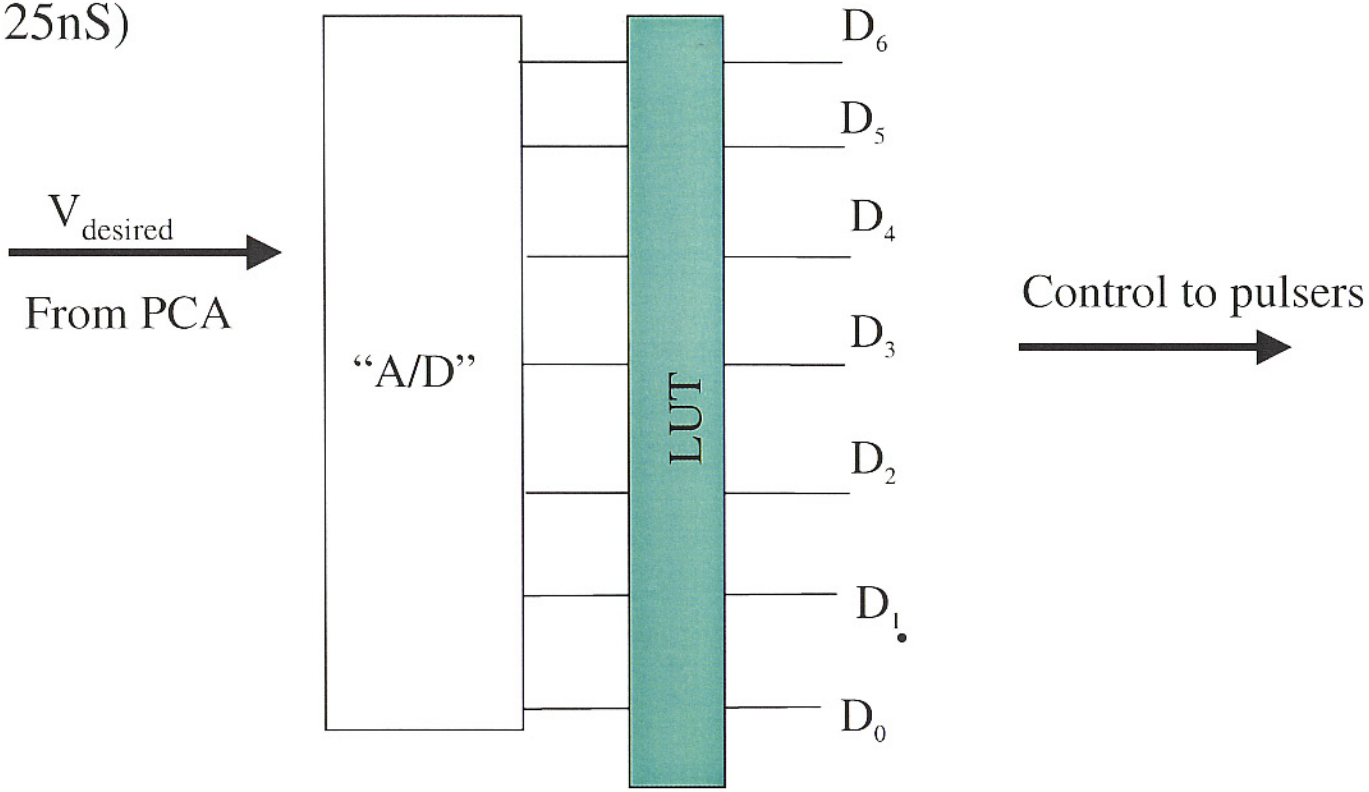


Pulse-width Transfer Function for the Digital Modulation Stages

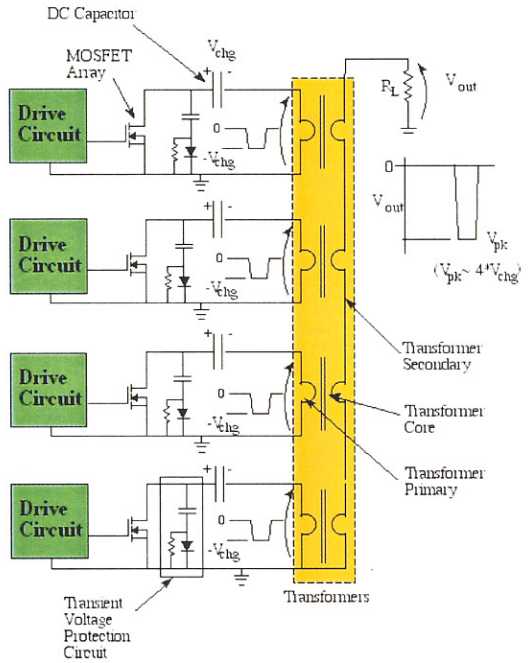


Pulse-width Transfer Function for the Digital Modulation Stages

- A Look-up table is used for narrow pulse widths (15 – 25nS)

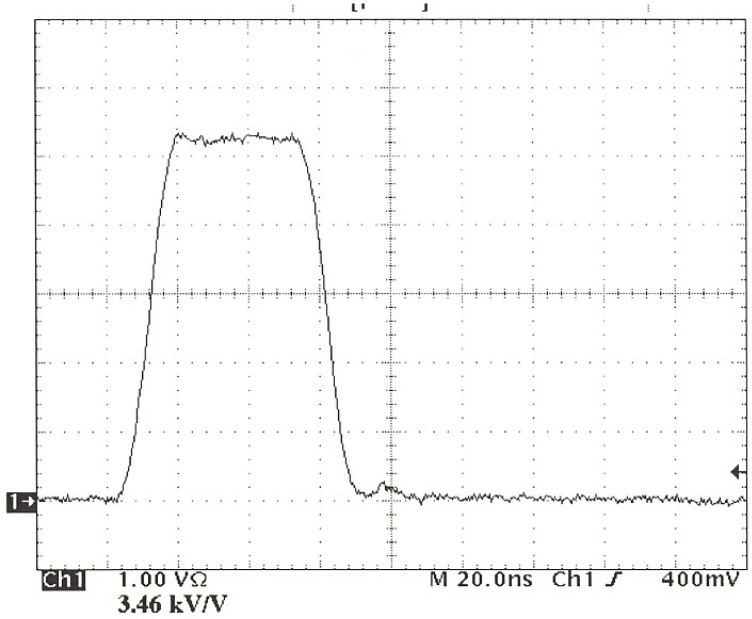


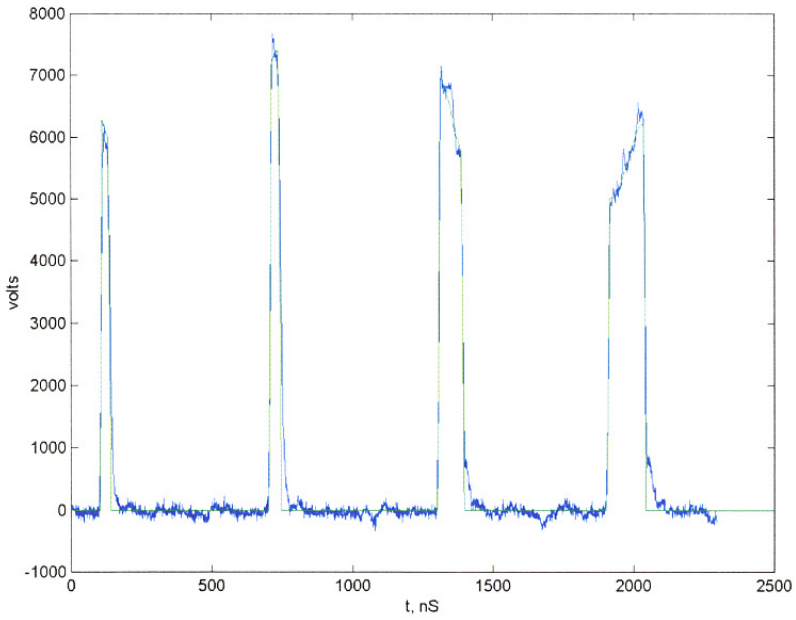
LLNL 20kV Solid-State Pulse Generators



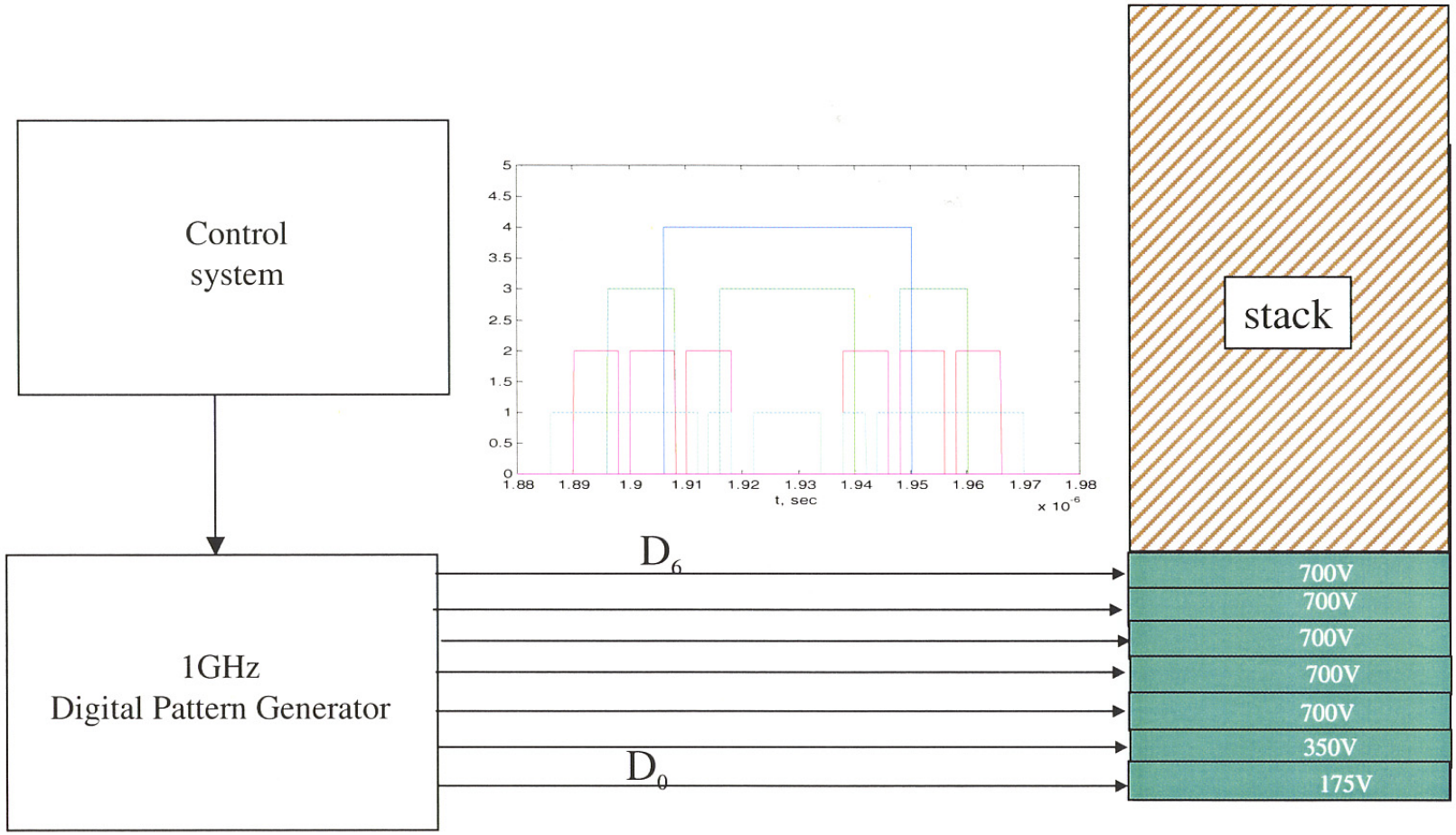
LLNL 20kV Solid-State Pulse Generators

- Pulsewidth and Amplitude Control
  - 20 – 120nS, 10nS rise/fall
  - 1-4 pulses, 200nS min spacing
  - 16 – 20kV into 50Ω
    - amplitude adjustable (10MHz BW)
  - 33 stages
    - Scaleable by adjusting the number of stages
    - (4-8kV for ETA-II, 50kV achieved)



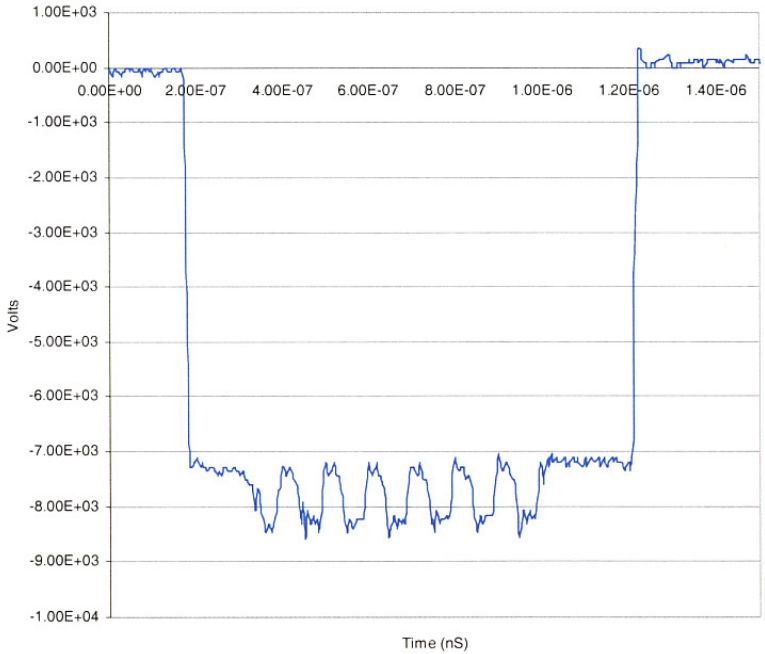


Digital Pattern Generation
"D/A Converter"

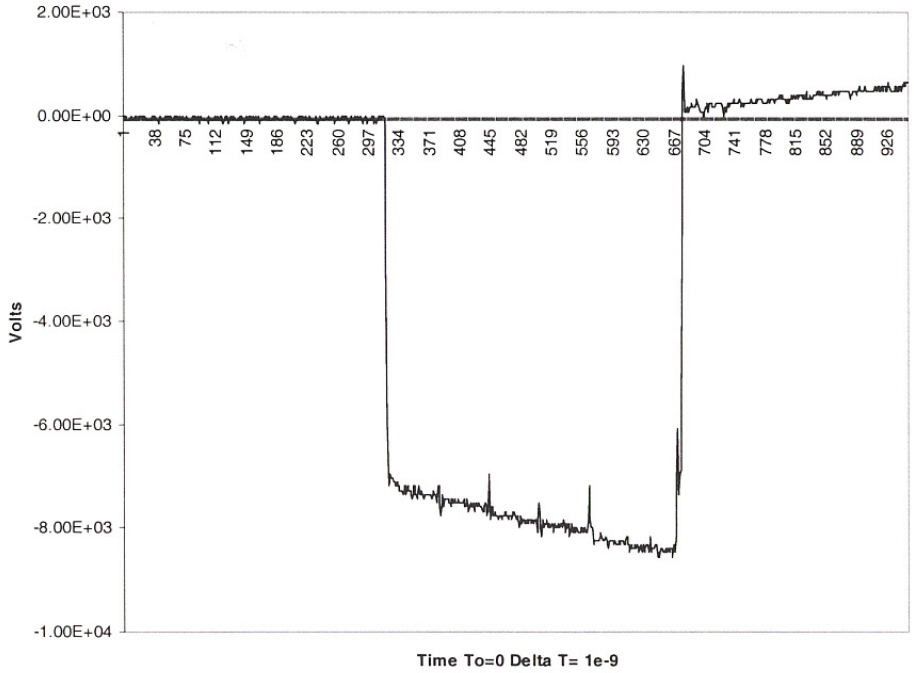


Digital Modulation Control

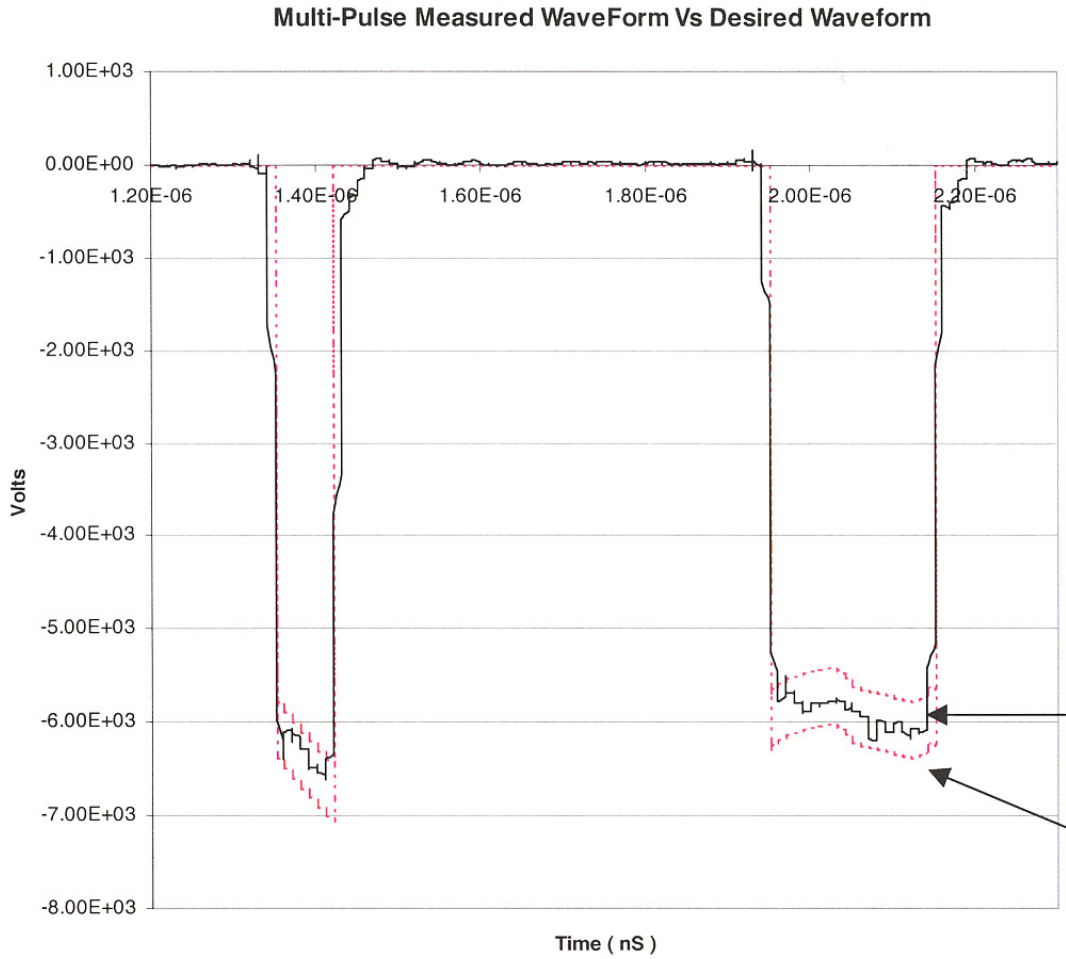
10MHz SineWave Modulated on Top of a 1μS Stack Pulse



350nS Ramp Modulated 0V-1725V on top of Stack Pulse



Digital Modulation Control

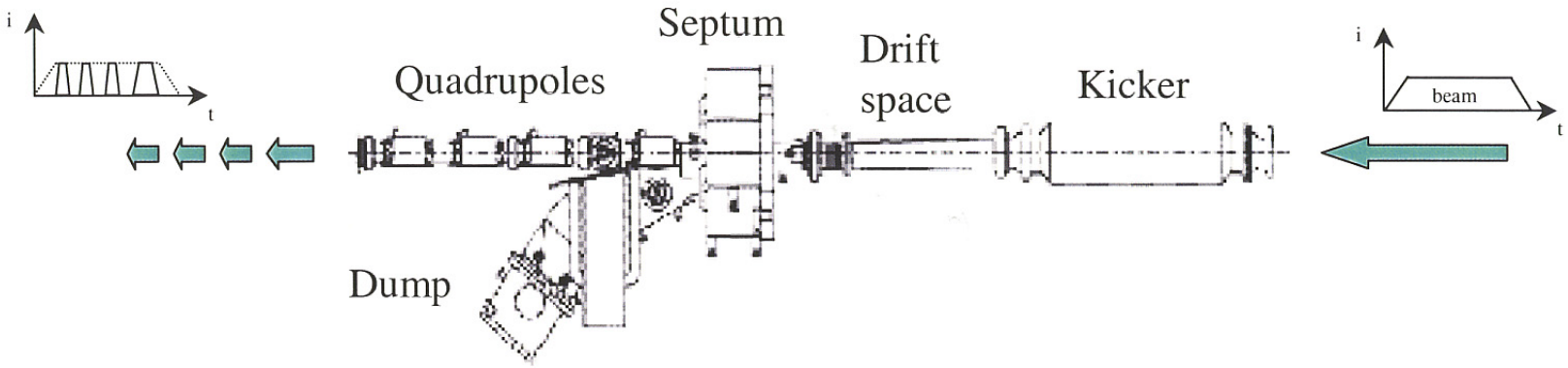


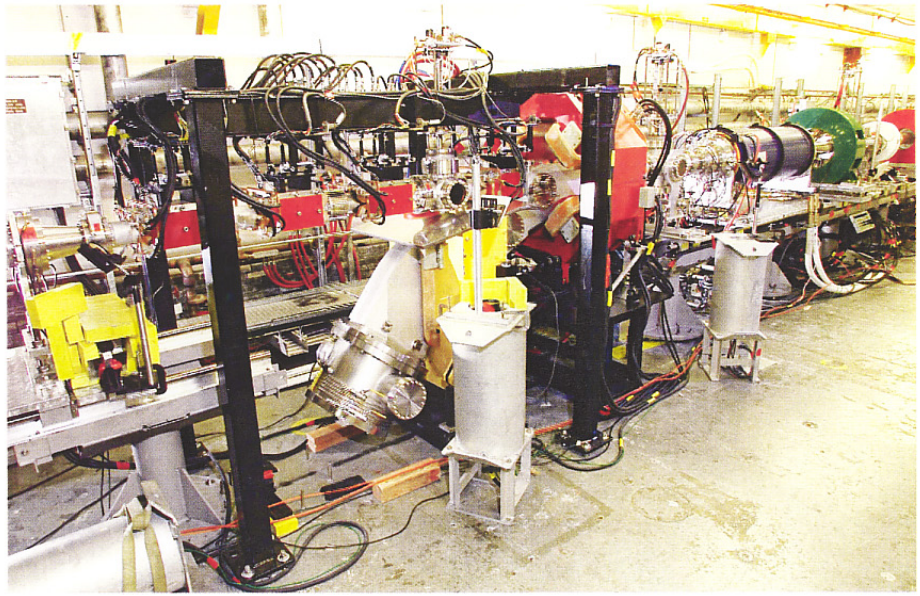
Seven digital modulation stages on top of a 6kV adder assembly

measured

desired voltage window

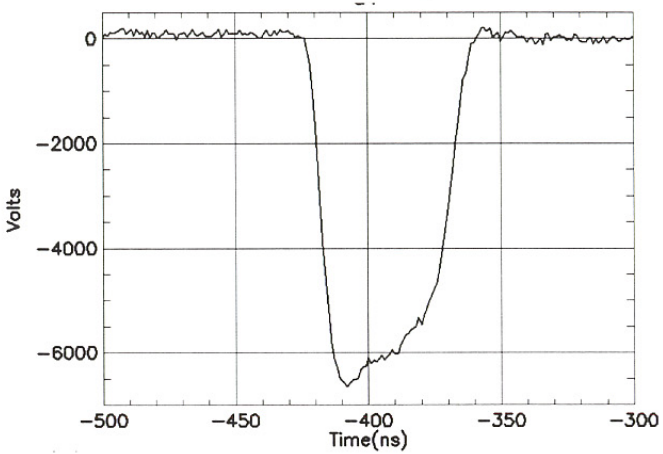
Kicker Experiments on ETA-II



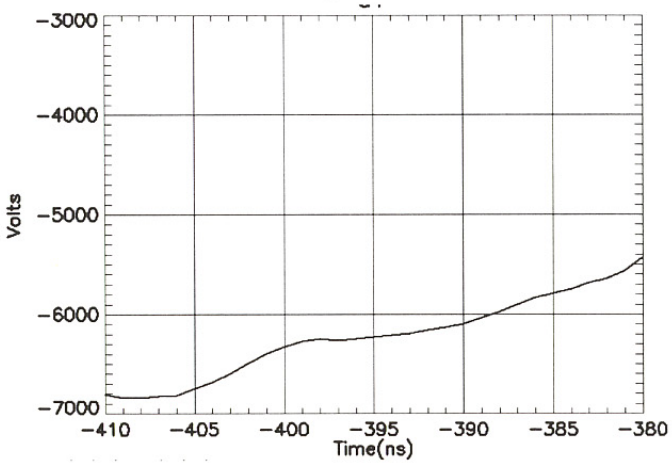


Kicker Exit

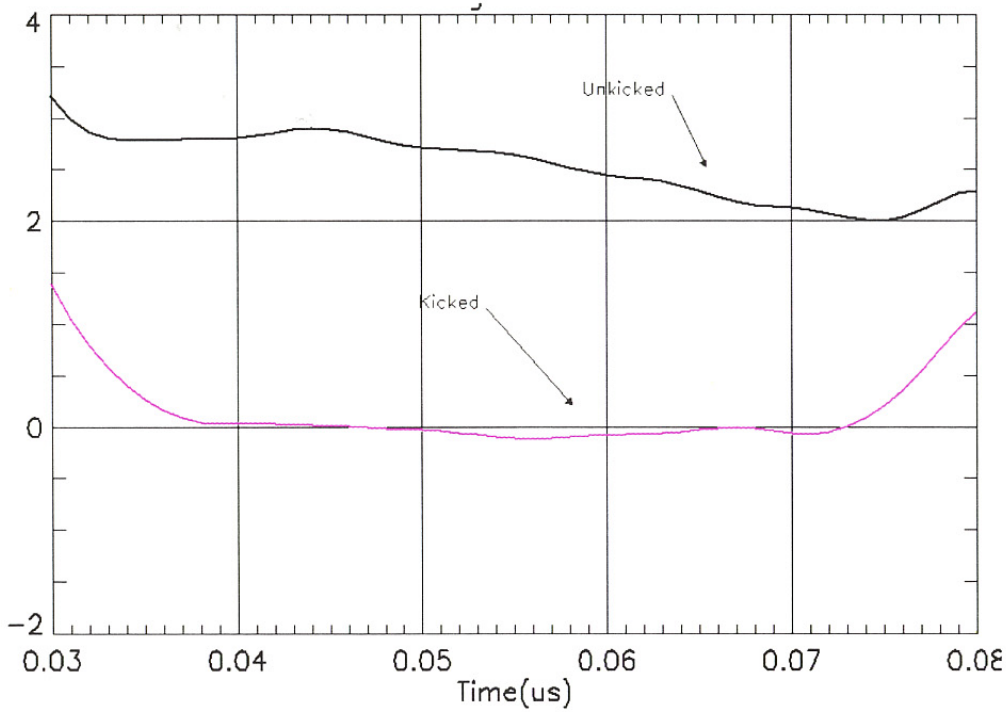
Pulser output



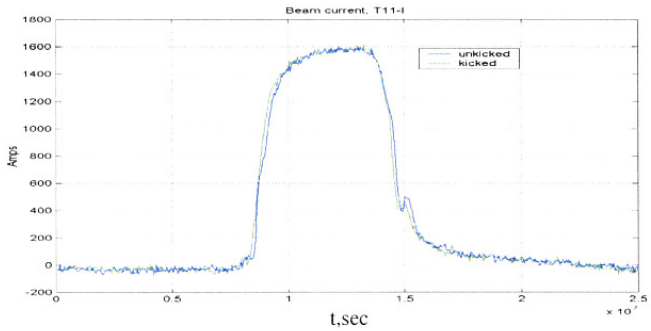
Pulser output (zoomed)



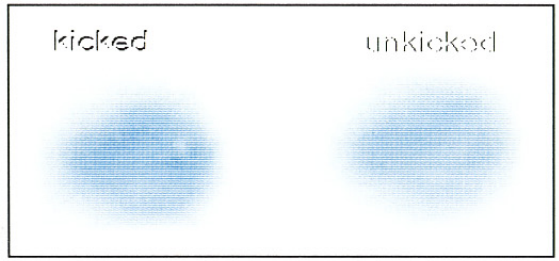
Beam position, cm



Binary kick on ETA-II (square kicker pulse)

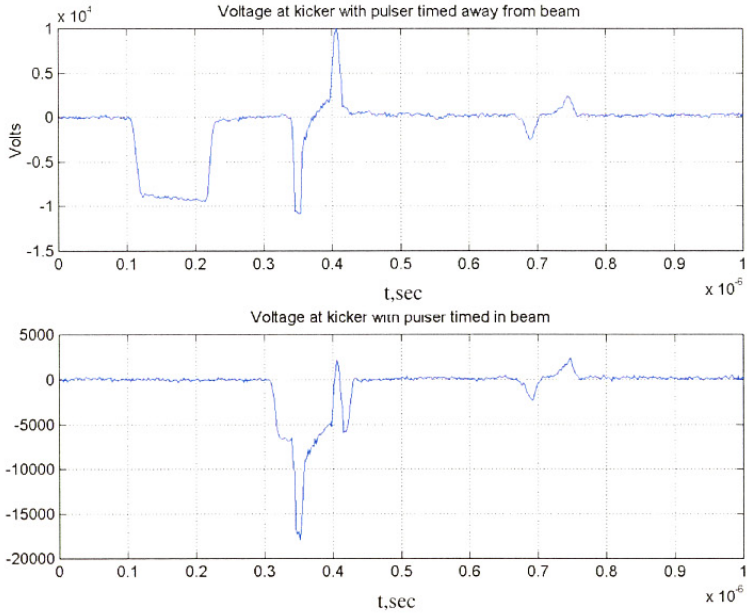


Beam current at entrance and exit of kicker ib=1.6kA

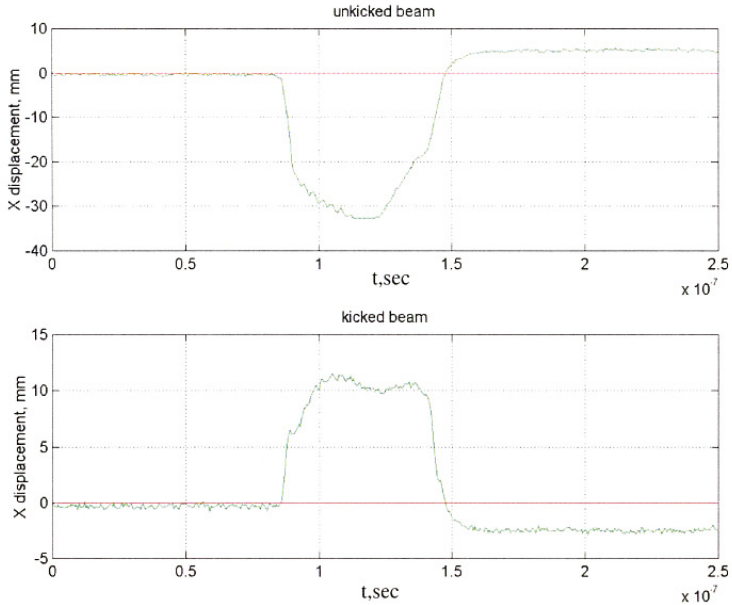


Foil image (4cm kick)

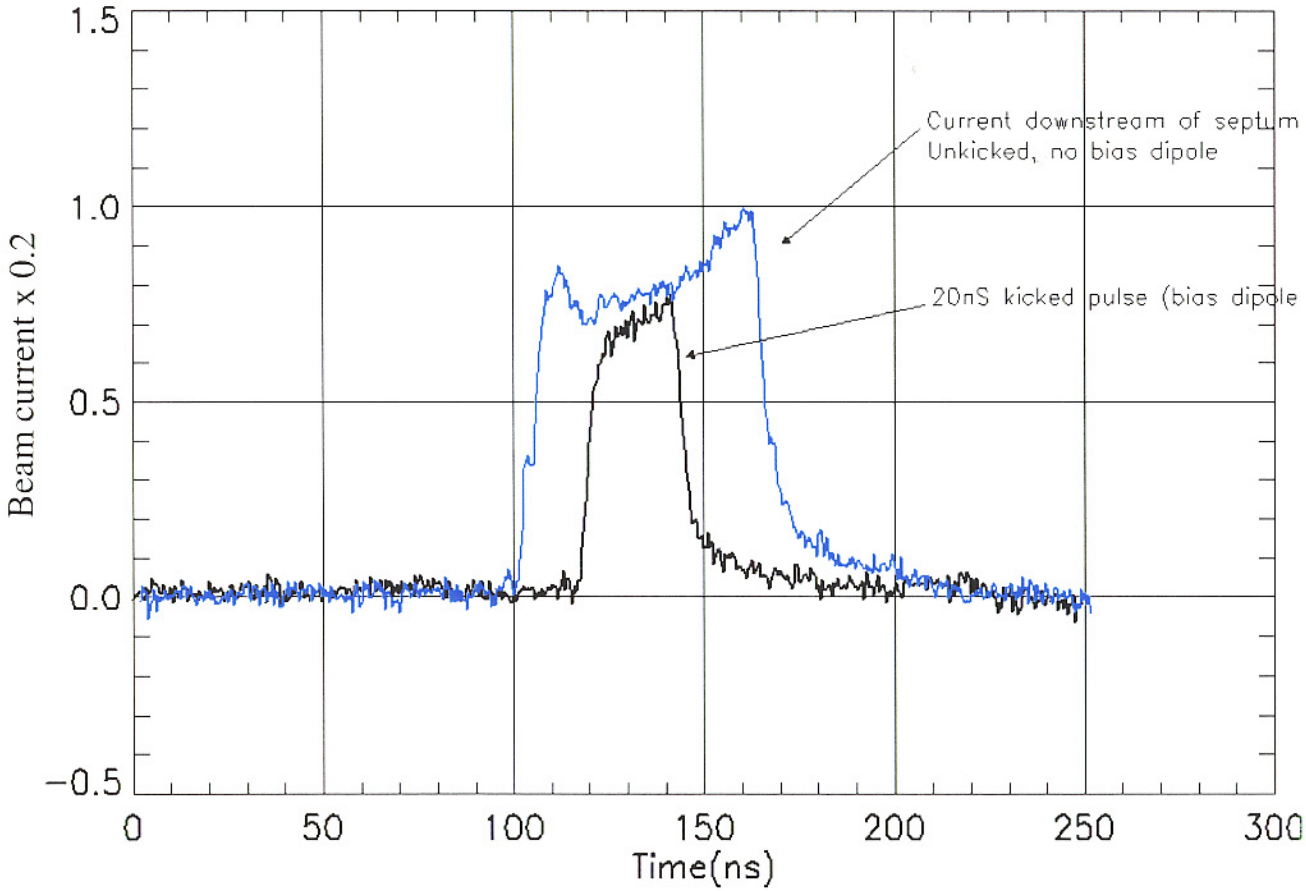
Voltage at kicker (one side)



Beam displacement downstream of kicker

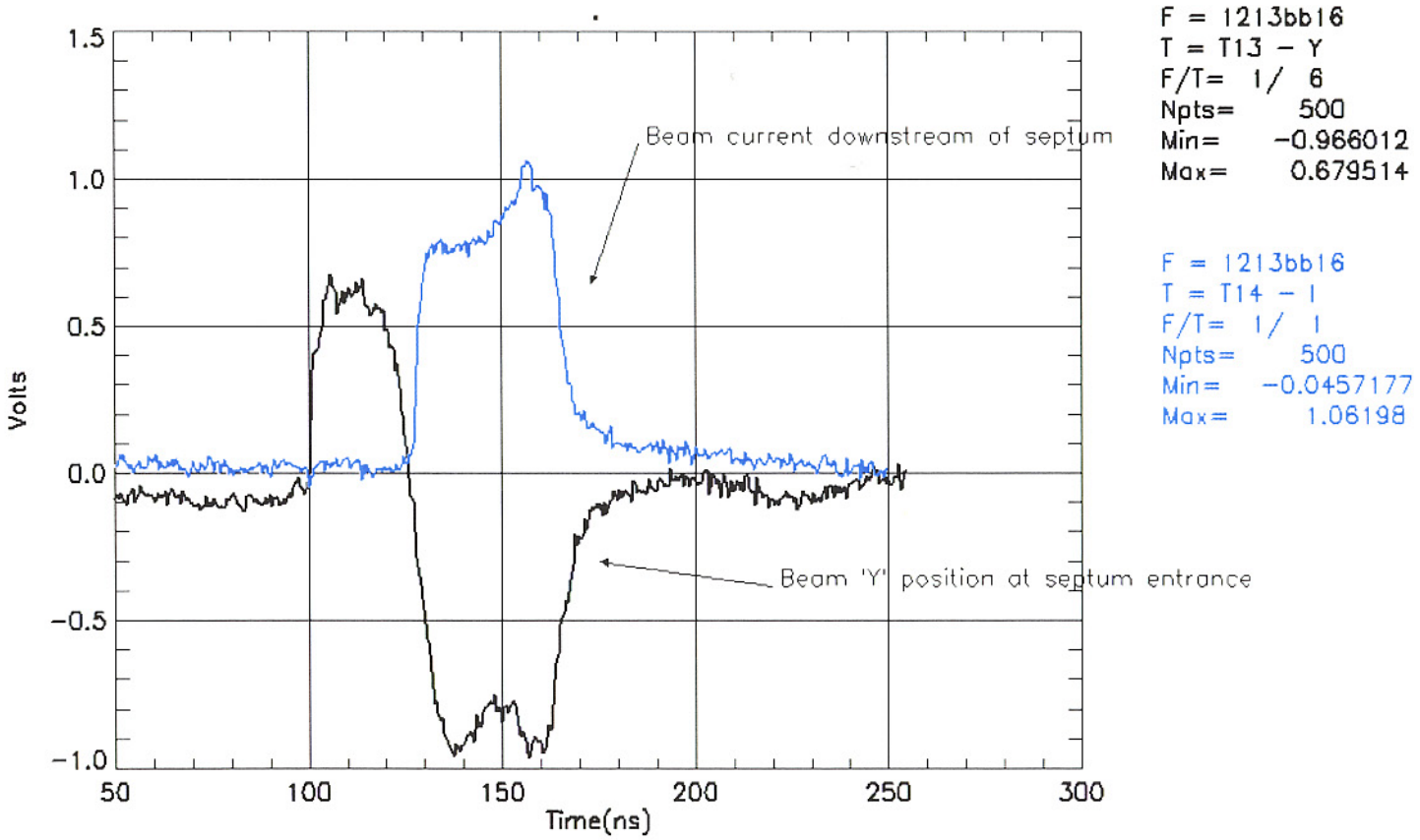


Kicked Beam Past Septum



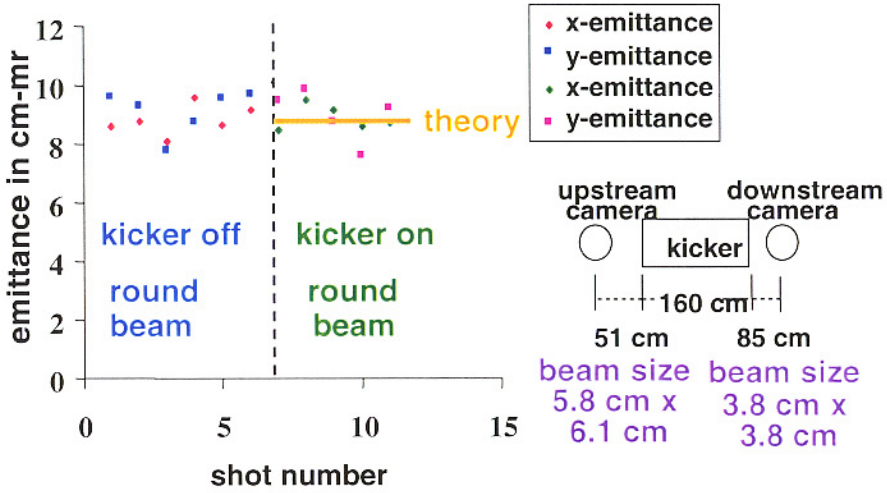
Note:
Transport element spacing set for 20MeV. The 6MeV ETA-II beam was passed through current-limiting apertures to reduce space charge effects

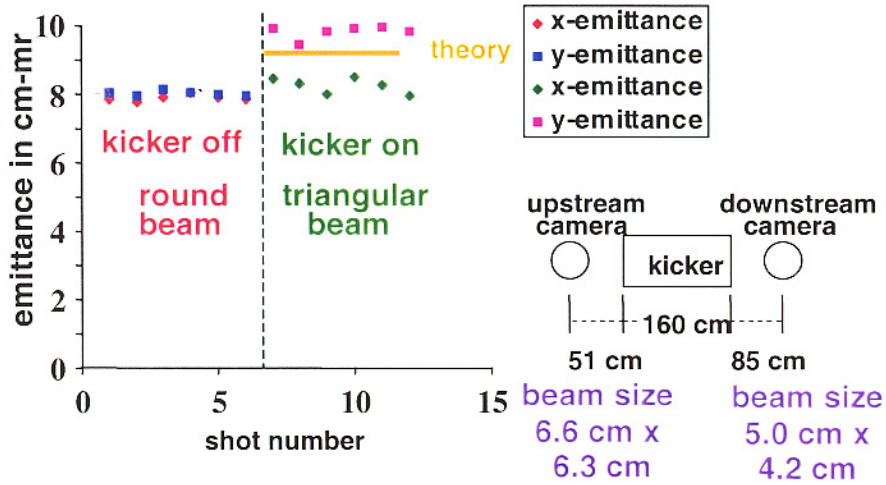
Kicker Switching Time

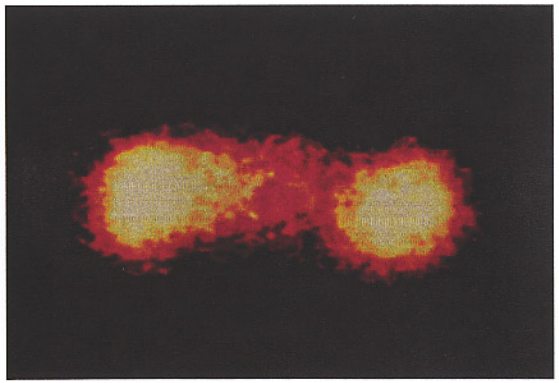


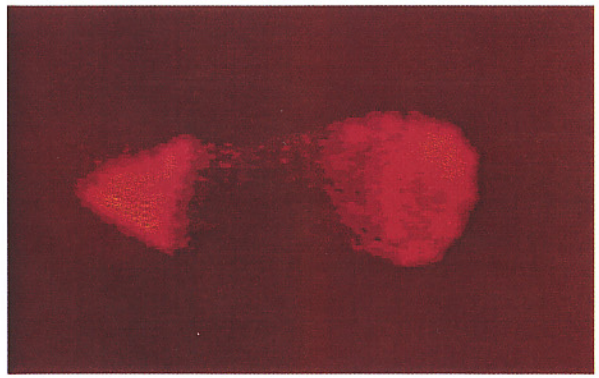
Kicker sextupole moment can lead to emittance growth for large beams

1900 Amperes, 5.7 MeV







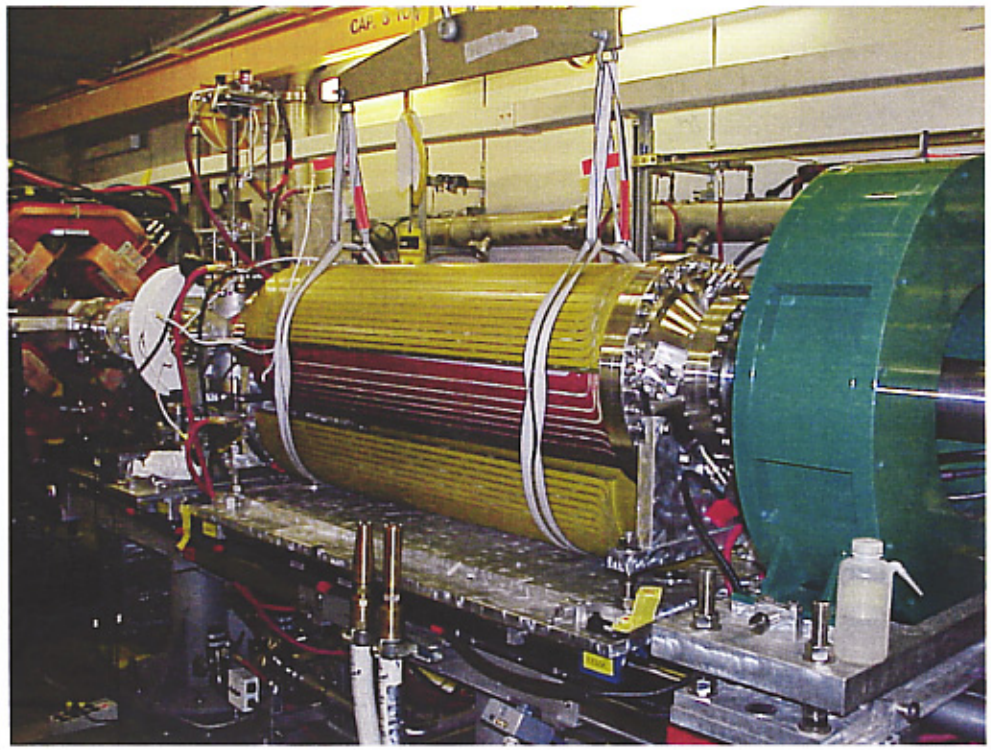


Judy Chen
Jim Watson

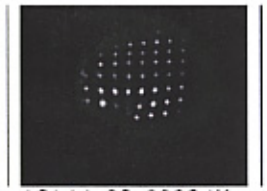
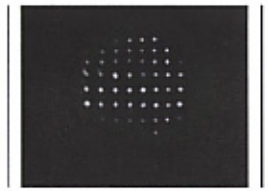
Beam Research Program

NNSA

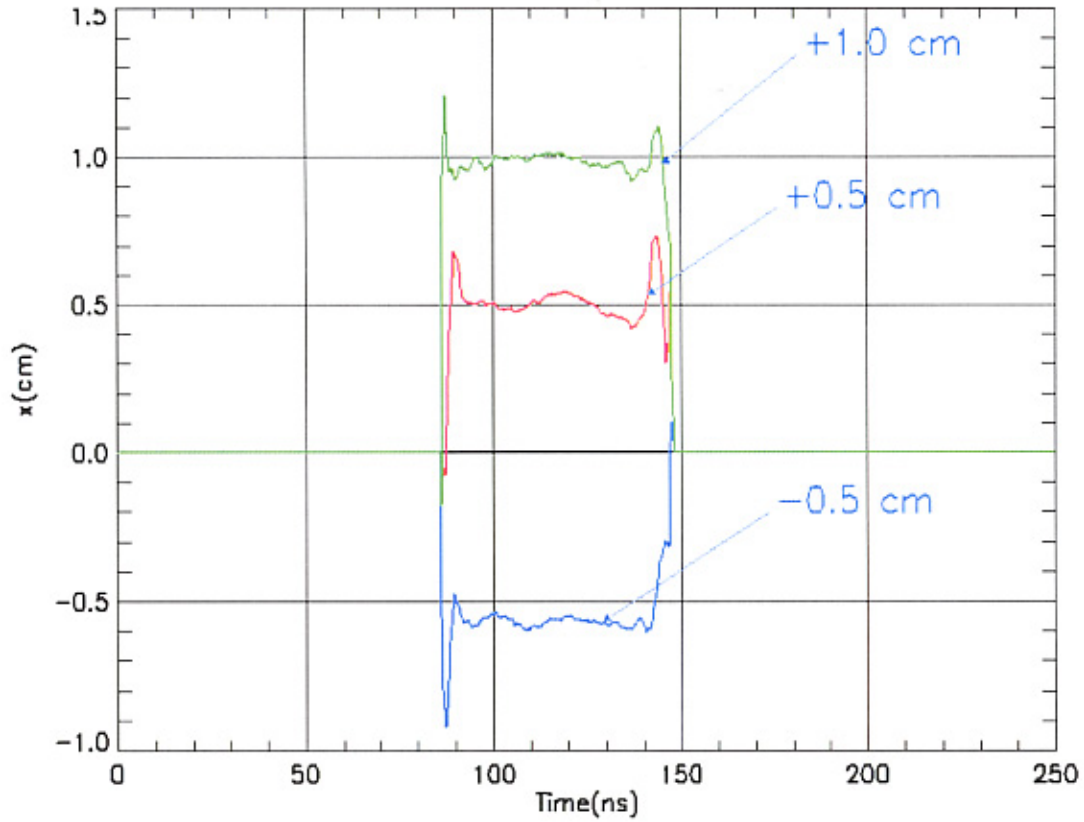
Sextupole and Dipole Magnets



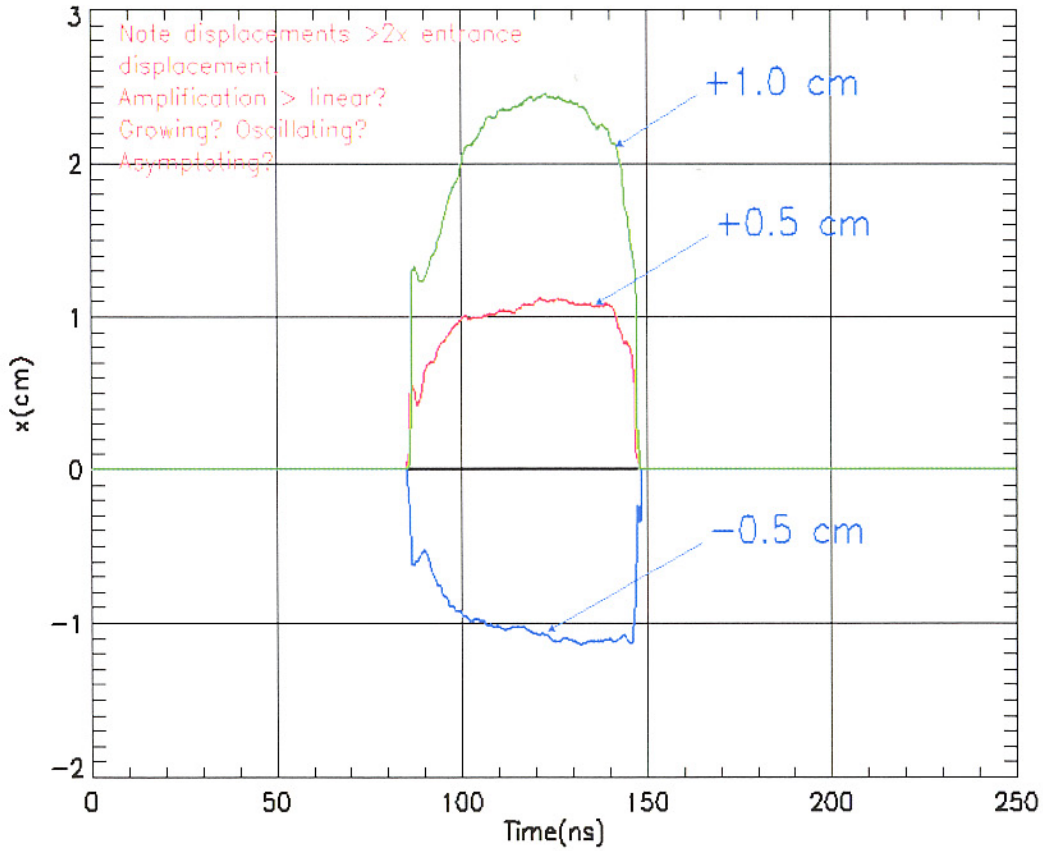
Mitigation of Emittance Growth through Kicker with Sextupole Correction

	Beam profile	Pepperpot Emittance Diagnostic
Unkicked	 1187dc05.tif	 1214dp01_0003.tif
kicked	 1187ac01.tif	 1214dp02_0008.tif
Kicked with sextupole correction	 1187ac02.tif	 1214dp04_0003.tif

Beam-induced Steering Measurement
Beam Position at Kicker Entrance

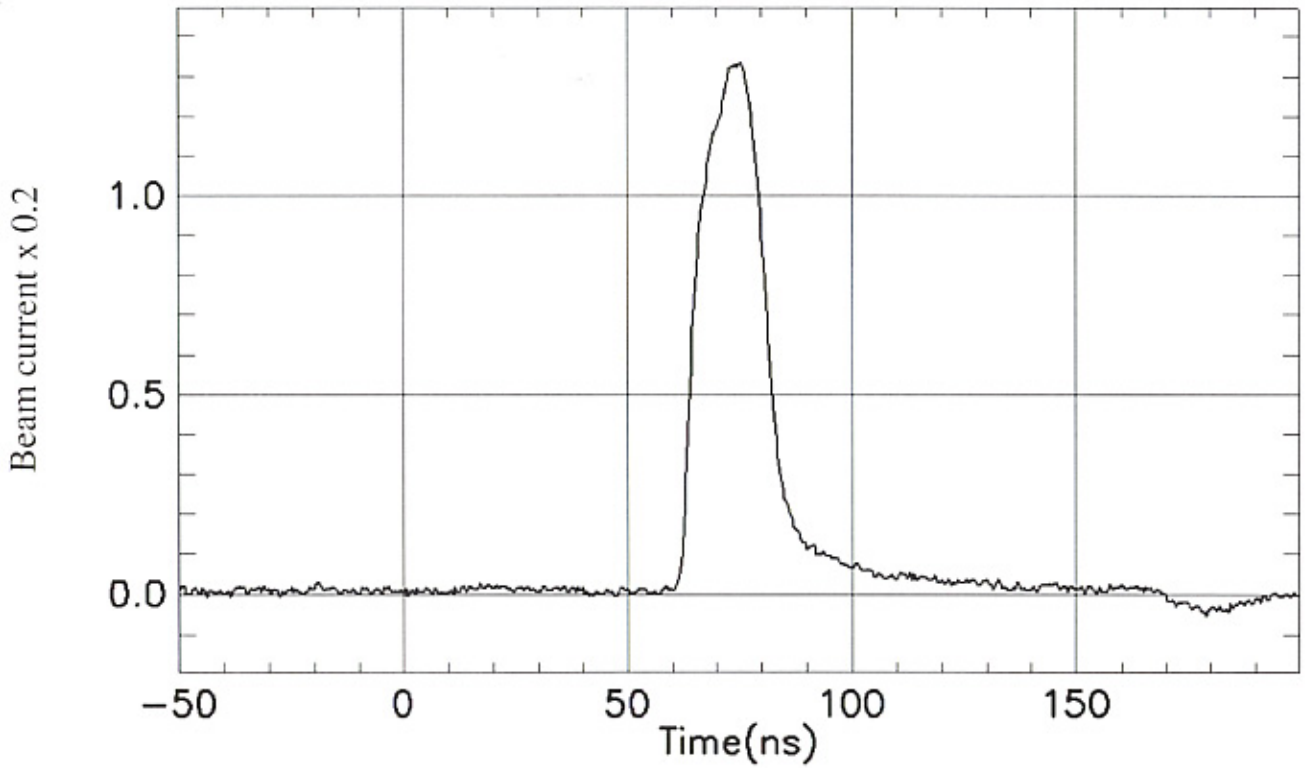


Beam-induced Steering Measurement
Beam Position at Kicker Exit



Spot Size Dilution Measurement
Narrow Kicked Beam

- Approx. 18nS FWHM at nominal current transported on ETA-II



Spot Size Dilution From Kicker Switching

Beam profile past kicker and septum for narrow beam

Unkicked

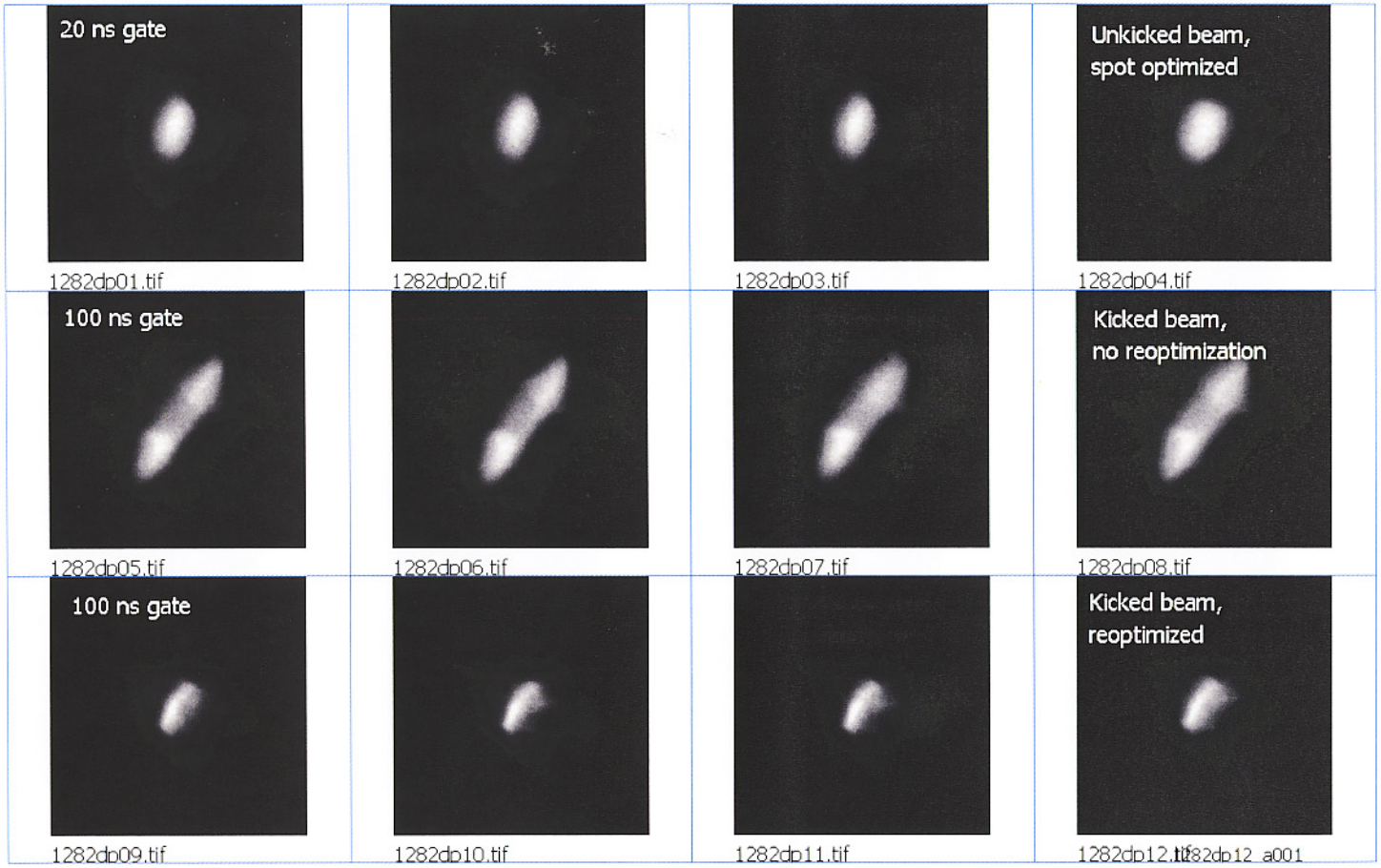
1200bc02

Kicked

1200bc03

Minimized Beam Slew Past Kicker with Optimized Quadrupole Tune

Foil downstream from quad transport



Minimized Beam Slew Past Kicker with Optimized Quadrupole Tune