Solid State Active Reset Induction Technology to Accelerate kA Electron Beam

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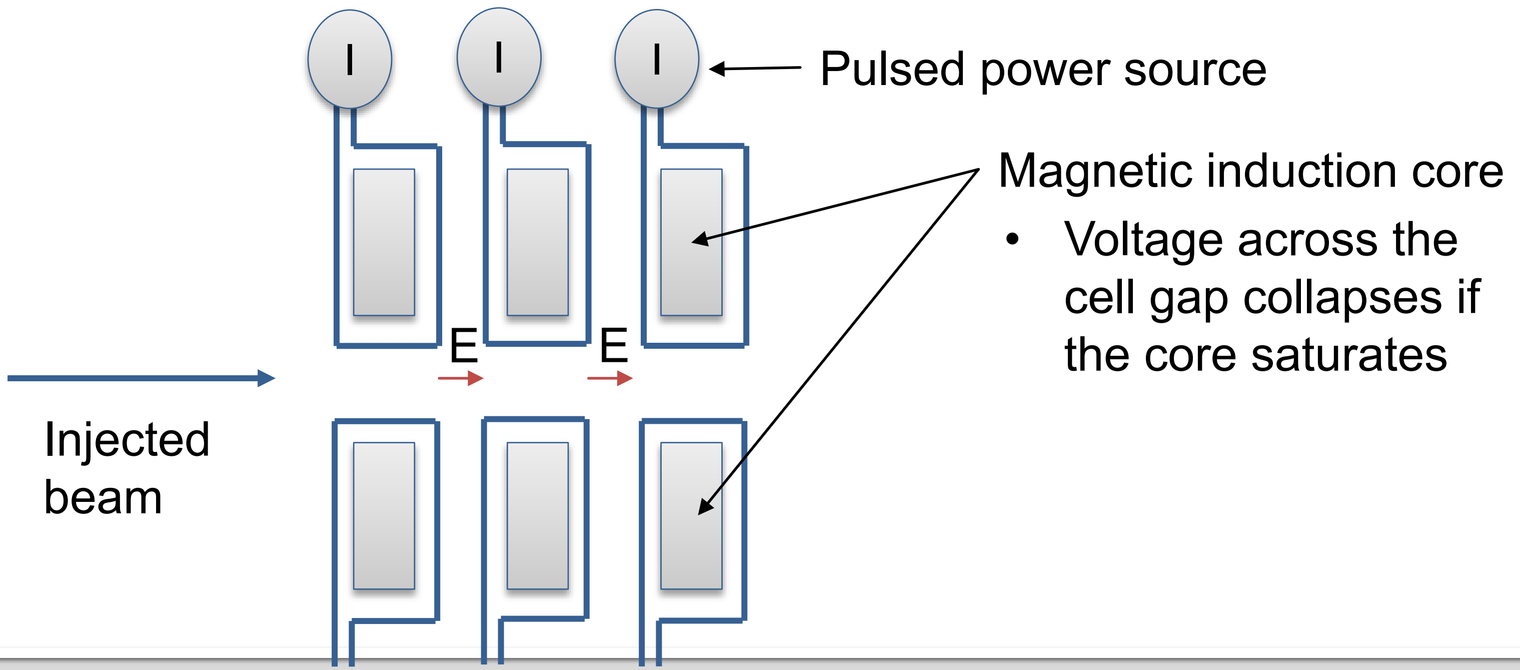
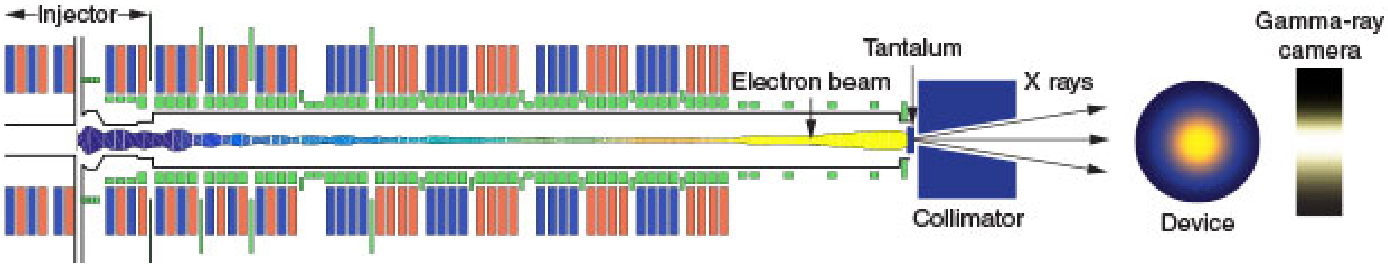
Linear Induction Accelerators produce high current, pulsed electron beams

- kAs of current for timescales on the order of 10 - 1000 ns
- Conventional pulsed power produces a single pulse
- Modern pulsed power such as solid state pulsed power produces multiple pulses
- Applications of LIAs include flash radiography, heavy ion fusion, medical sources



An X-radiographic movie capability will allow access to more physics during a single experiment

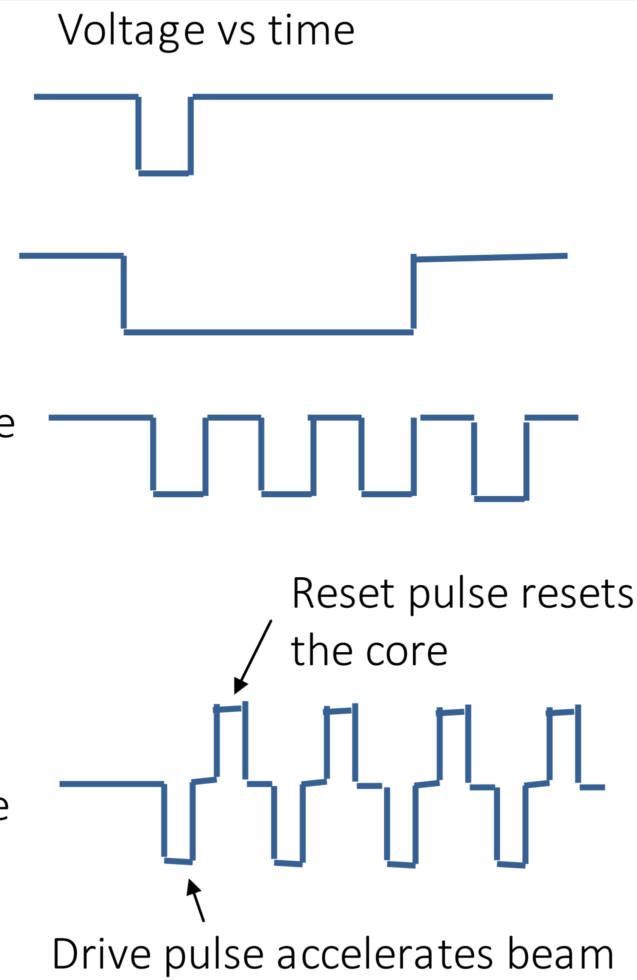
- For flash radiography, create a bremsstrahlung x-ray source by slamming the electron beam into a metal target
- Each electron beam pulse creates a burst of x-rays that generate one image



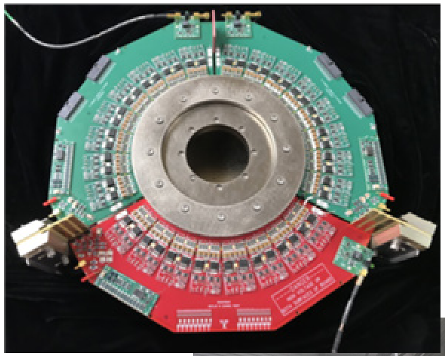
- Multiple images can create an x-ray movie
- X-ray cinematography will allow access to more physics during a single experiment

To generate many pulses using an LIA, we need to reset the core in between pulses

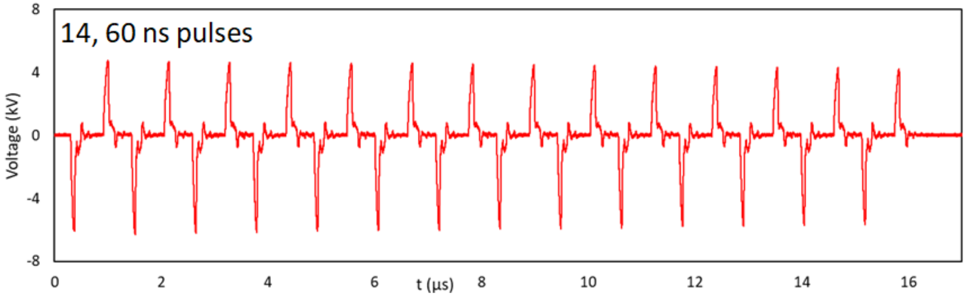
- Fire cells at different times to accelerate multiple pulses
  - FXR double pulse operation uses this approach
- Produce one long pulse and then chop the beam
  - DARHT-2 uses this approach
- Increase the volume and magnetic permeability of the LIA cell cores to provide larger volt*sec cells
  - Scorpius machine uses this approach
- Reset the core between pulses (active reset)
  - Requires a pulsed power source that produce a negative voltage pulse to accelerate the electron beam and a positive voltage pulse to reset the core in the cell
  - The core magnetization is "re-used" to support an arbitrary number of pulses

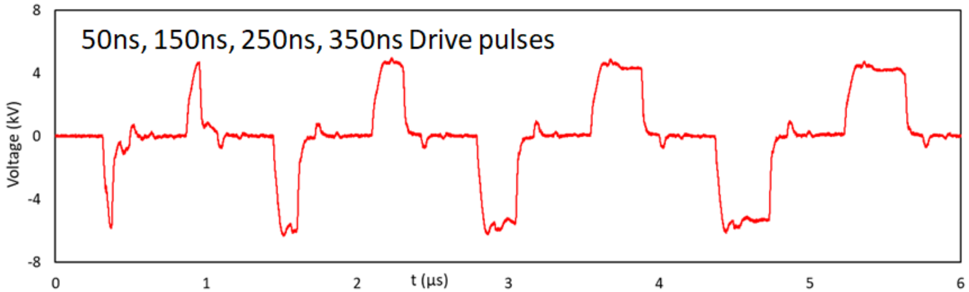


We have developed a programmable bipolar solid state pulsed power source to drive and reset induction cells



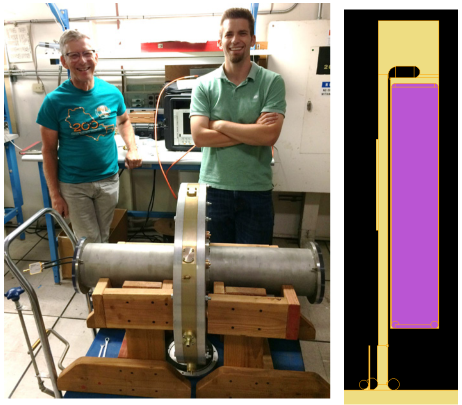
- The pulsers have programmable pulse width and pulse separation
- Data show for pulser connected to an active reset induction cell

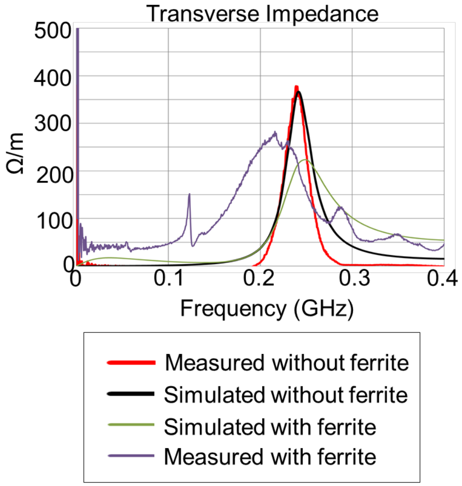




The BSSPP drive a custom induction cell designed using experimentally validated codes to minimize cell transverse impedance

Code validation experiment





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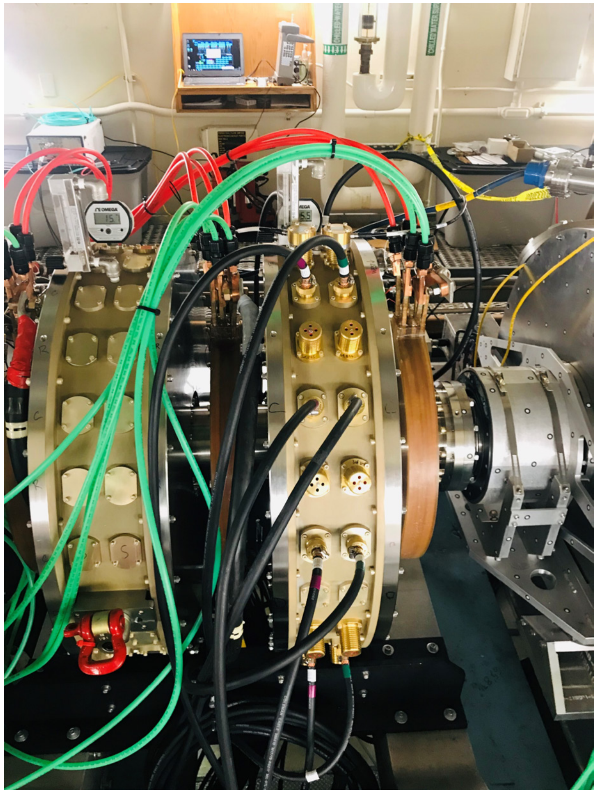
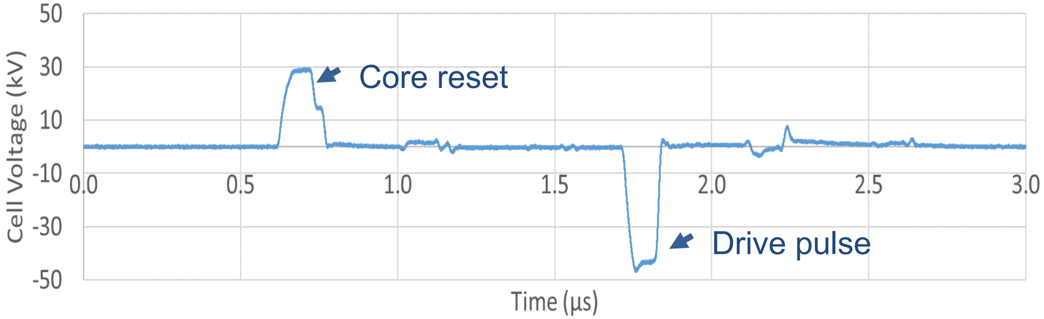


Active reset induction accelerator cells

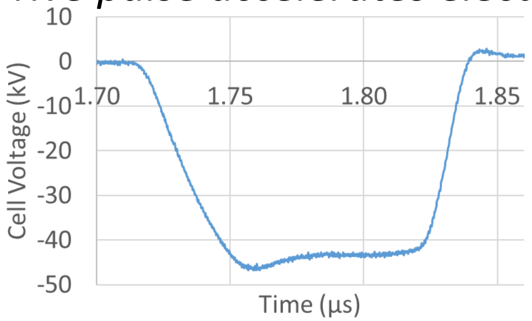
- Minimize the beam-breakup instability
- The LIA can use a larger number of low voltage accelerating gaps
- Electrodes are designed for operation with both negative and positive voltages
- Inductive core material is sized for a single pulse and is reset between pulses

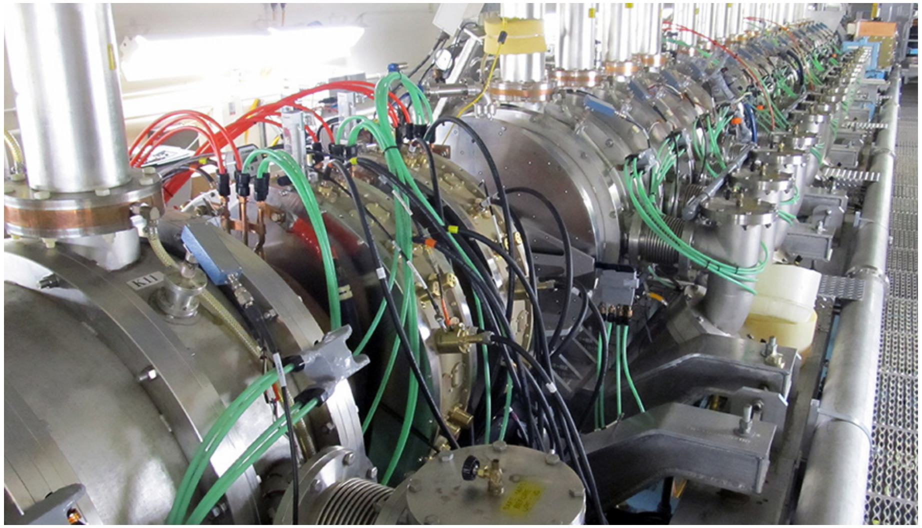
The bipolar pulsers and active reset cells were installed on the FXR machine for integration testing of active reset technology

Vacuum test of cell on beamline without beam



Drive pulse accelerates electrons





Active reset cells installed at FXR

Pulsed Power Units installed at FXR

New solenoids were designed to match the electron beam focusing

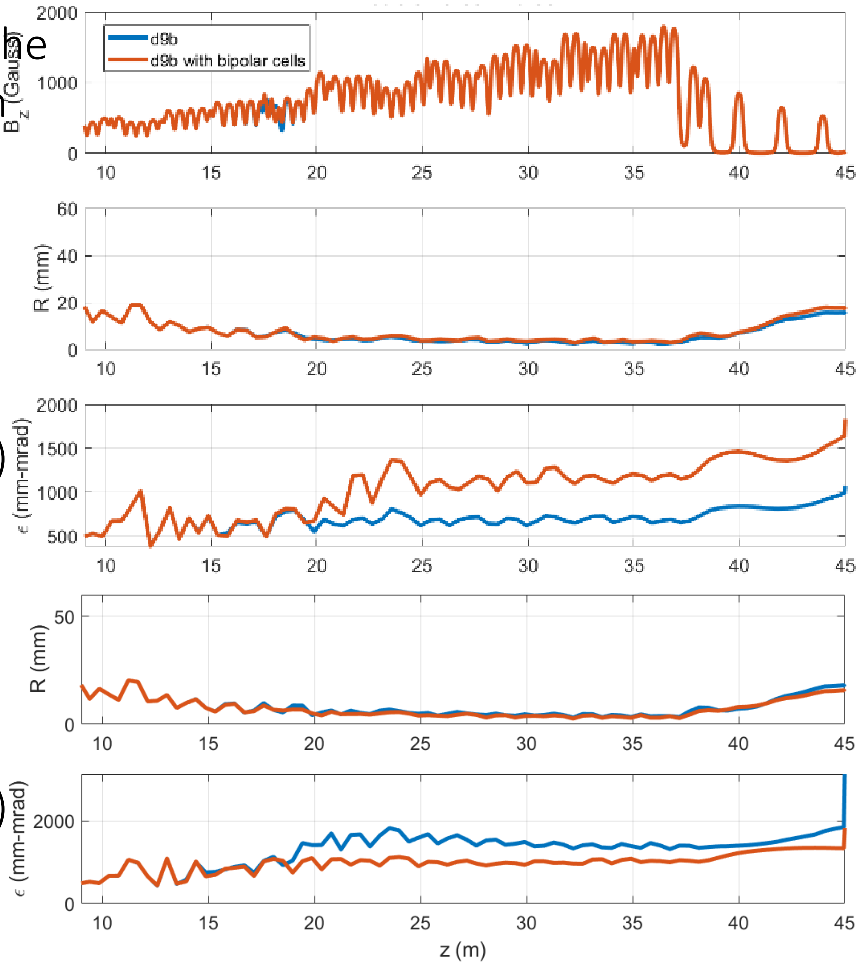
B_z (Gauss) is the same for both pulses

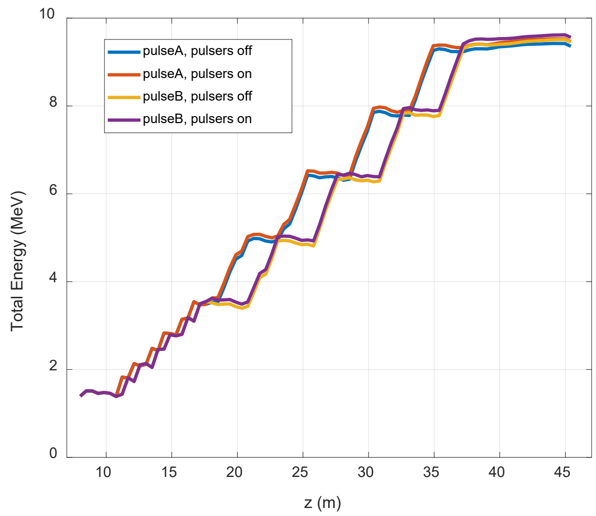
R (mm) for Pulse A

ε_n (mm-mrad) for Pulse A

R (mm) for Pulse B

ε_n (mm-mrad) for Pulse B



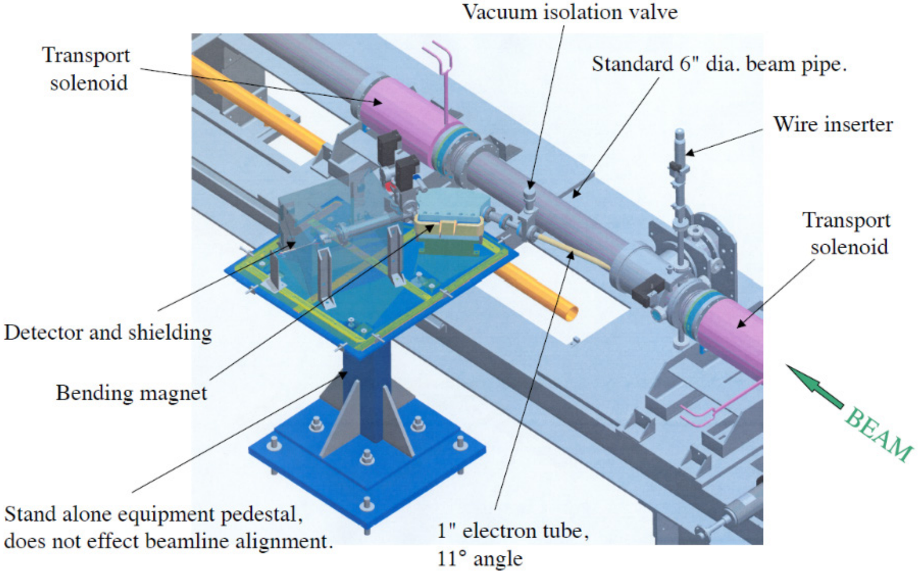


- Each pulse has a different acceleration profile, but the same magnetic lattice
- Solenoids were optimized to match the transport for single pulse operation, but do a reasonable job for double pulse too

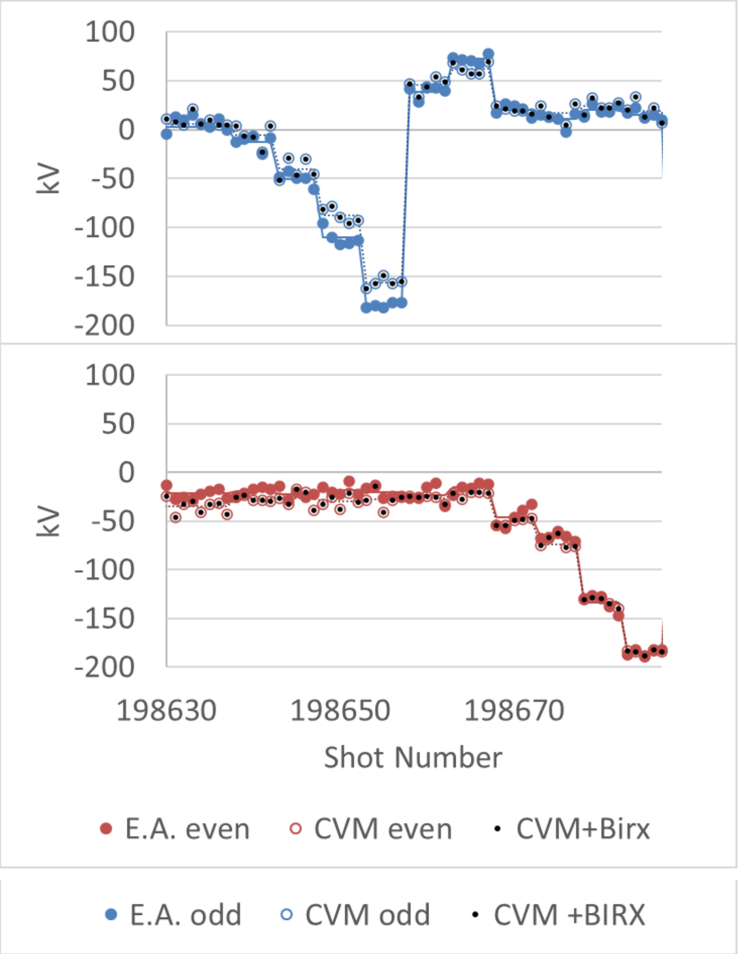
Scattering wire spectrometer measured the electron beam energy

$$E = G\left(\frac{V_a - V_b}{V_a + V_b}\right) + E_{center}$$

- Look at <E> during a pulse and E(t)

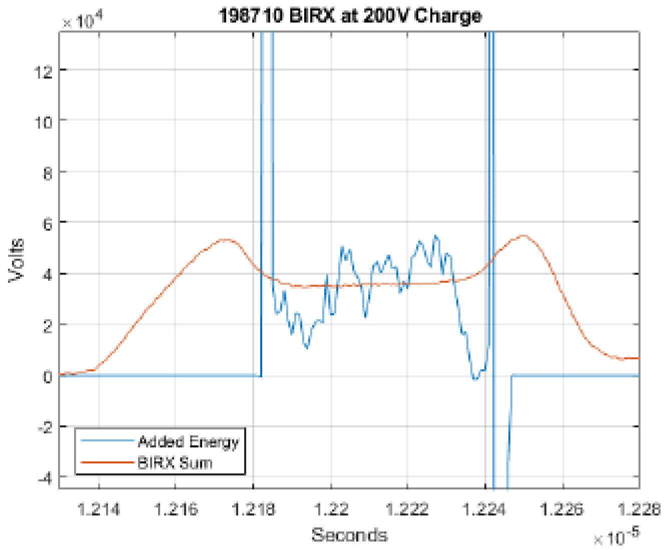


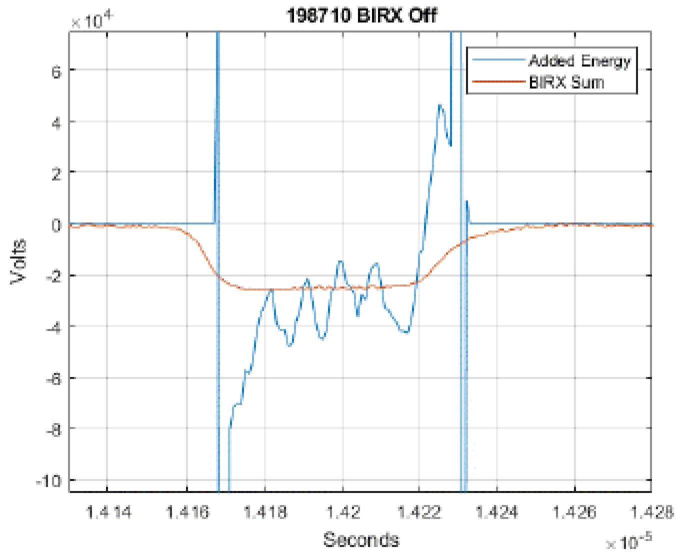
Varied the FXR cell voltage with the active reset cells shorted. Measurement from the energy analyzer show good agreement with the capacitive cell voltage monitors



The energy analyzer showed that the cell accelerated and decelerated the beam as expected

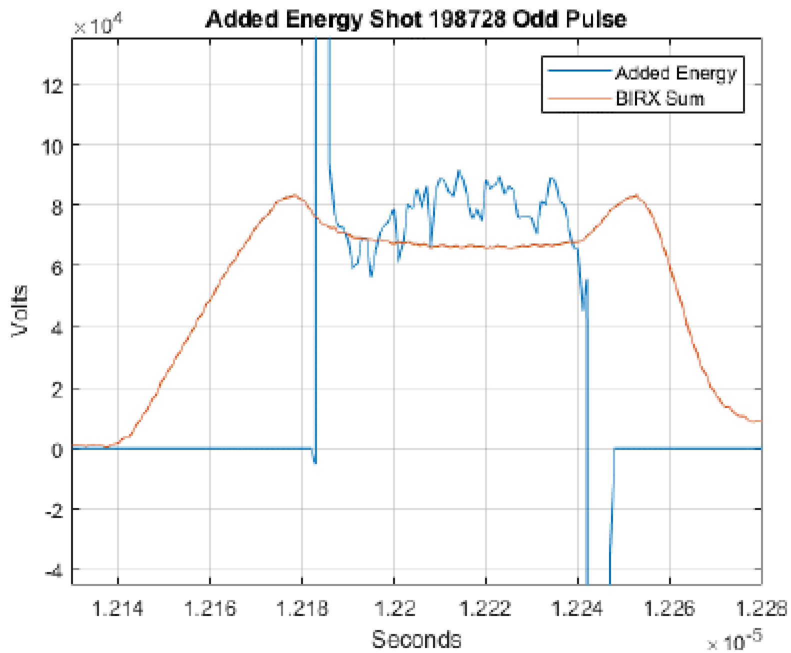
- Timed active reset cells to align with electron beam
- The voltage measured on the cell (orange) and measured energy gain of the beam during the beam duration
  - Working to improve the noise
  - The depression shows that the voltage pulse was longer than the beam pulse
- Also measured the beam loading caused by the cell when not energized.
  - Level of energy drain was as expected.



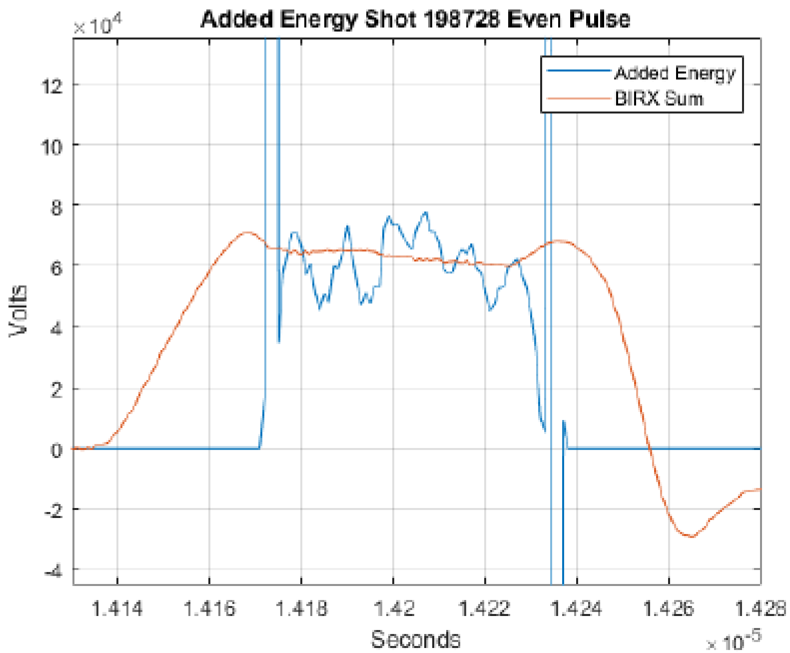


Demonstration of multiple pulses using same core material using active reset to accelerate beam

- Pulsed power generates a 4-pulse burst at ~ 1 MHz
- Opposite polarity pulses reset the cores between drive pulses
- Electron beams are accelerated the 1st and 3rd drive pulses

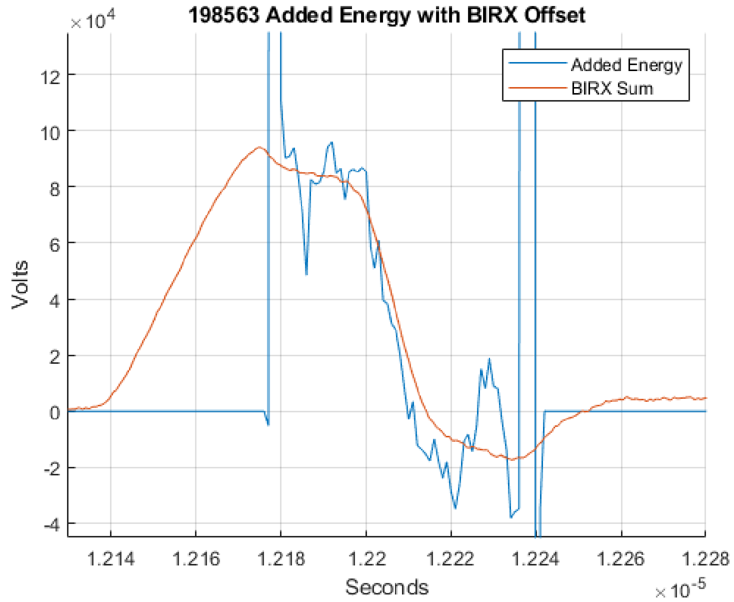


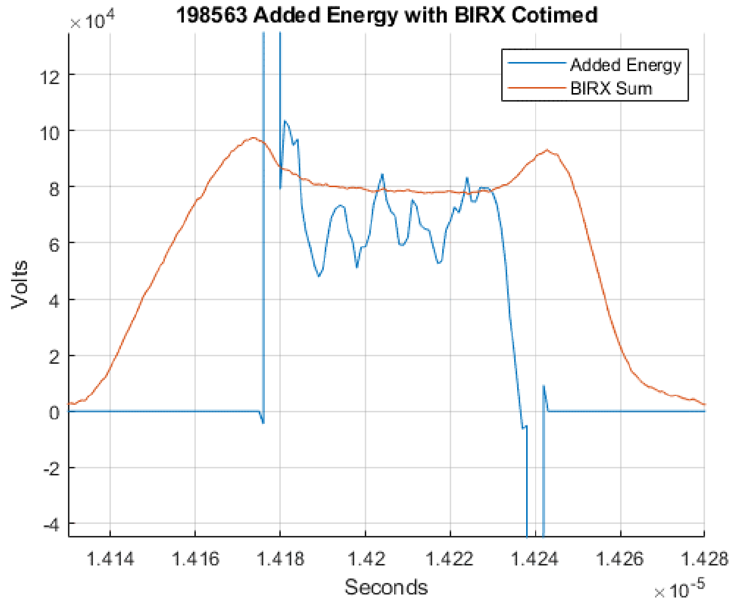
First pulse accelerates the odd electron beam



Third pulse accelerates the even electron beam. There is some droop in the applied voltage.

Offsetting the time between the drive pulse and the electron beam shows deceleration during the pulse





- Bipolar solid state pulsed power generates a 2-pulse burst
- First drive pulse is timed so that the electron beam sees the falling edge of the pulse
  - Induction cell voltage varies with time during the electron beam pulse
- Second drive pulse is co-timed with the electron beam

Conclusions

- Demonstrated pulsed power source capable of active reset
- Demonstrated the pulsed power actively reset the cells
- Demonstrated integration with LIA
- Measured acceleration of the electron beam with active reset technology integrated into FXR
  - Technology readiness level (TRL) – 7 demonstration
- Current work is building an electron injector using this technology

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