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Experimental Results and Circuit Modeling of an 18-brick LTD Cavity

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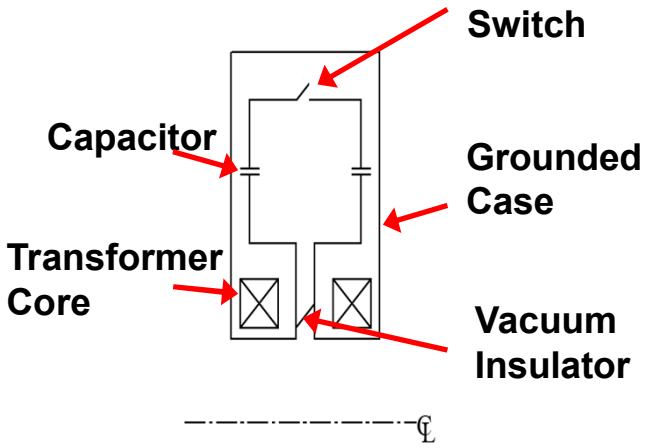
Outline

- Overview of design presented at PPPS 2013
- Projected performance
- Prototype cavity design
- Core loss characterization
- Circuit modeling
- Updated performance projection

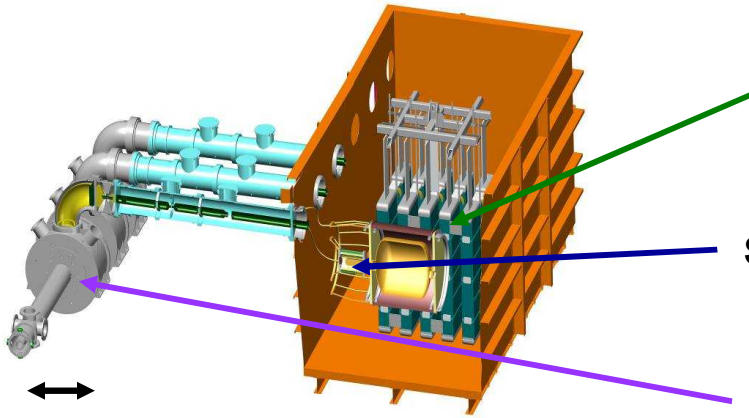
An LTD is a compact IVA with energy storage inside adder cavities

- The basic building block is a low inductance RLC circuit
- Eliminates the requirement for pulse compression stages typical of IVA accelerators
- Smaller footprint than comparable IVA

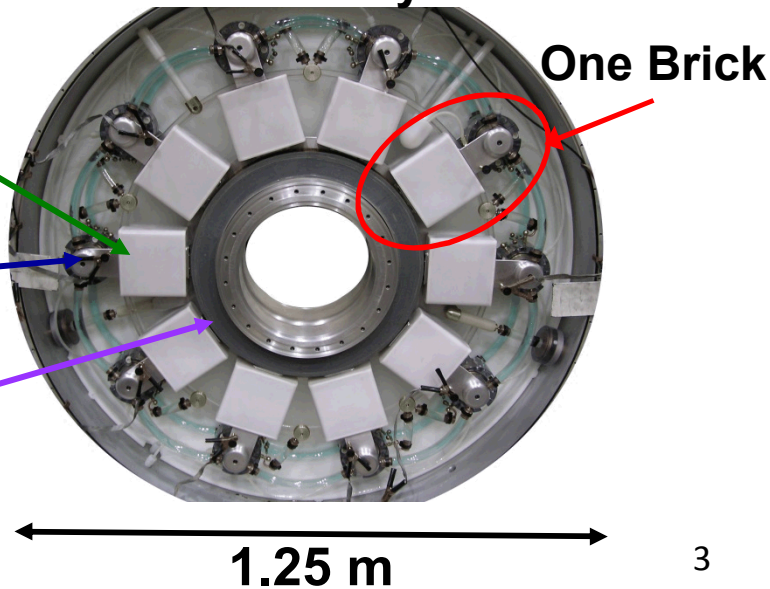


Linear Transformer Driver (LTD)

Induction Voltage Adder (IVA)



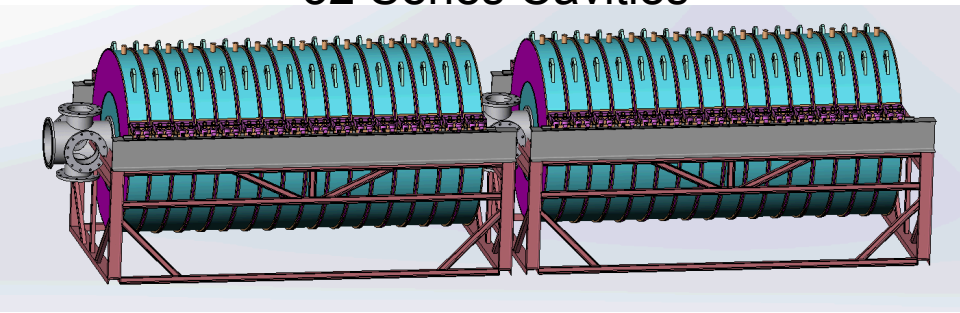
One Cavity

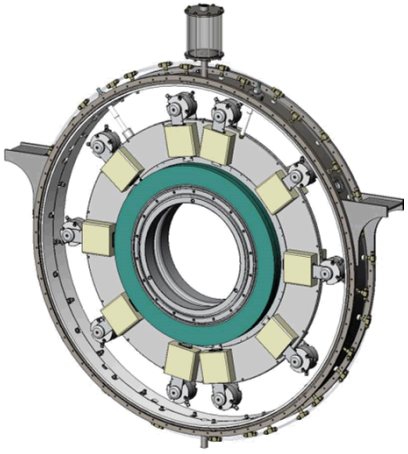


In 2013 we presented a reversible polarity LTD accelerator design

- Polarity reversal without disassembly
  - Swap charge cables at the power supplies
- Electrical pulse width 50-70 ns FWHM
- Positive polarity operation
  - Drive a 50-ohm electron beam diode
  - Peak voltage = 2.5 MV
  - No electron emission in the vacuum transmission line
- Negative polarity operation
  - Drive a 50-ohm electron beam diode
  - Peak voltage > 3.0 MV
  - Magnetically insulated output transmission line (MITL)
- Scalable to 7 MV with all 18 bricks
  - 7-MV accelerator would require 72 cavities

32 Series Cavities



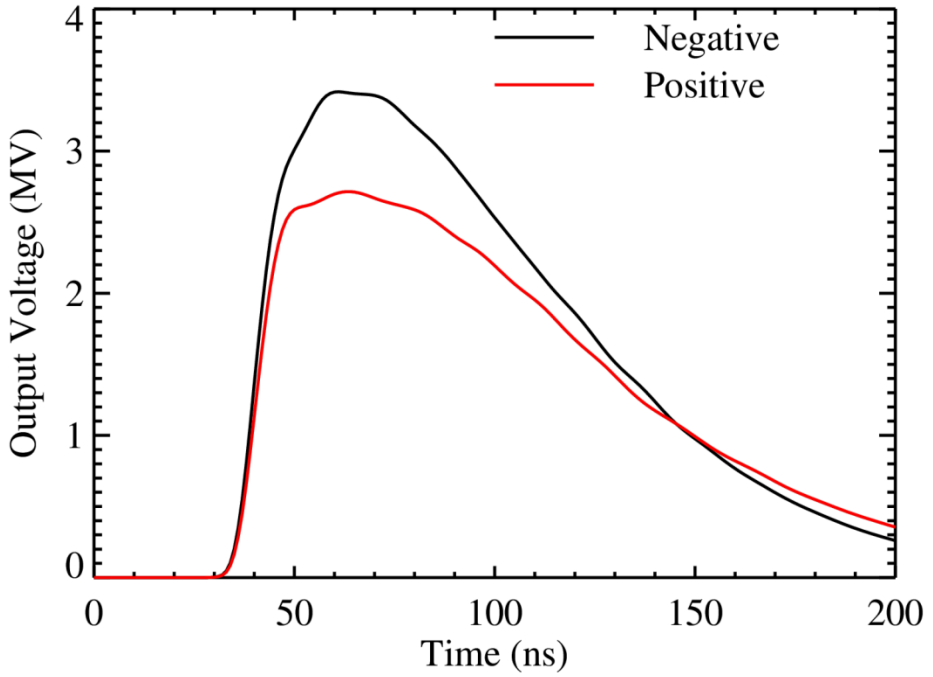


10 Bricks

18 Bricks

Circuit simulations predicted peak load voltage up to 3.5 MV

- Circuit Parameters
  - Num Cavities = 32
  - Num Bricks = 10
  - Capacitors = 12 nF
  - MITL impedance at load = 50 ohms
  - Diode impedance = 50 ohms
- LTD is capable of generating up to 3.5 MeV



An 18-brick prototype cavity was assembled and tested in 2014

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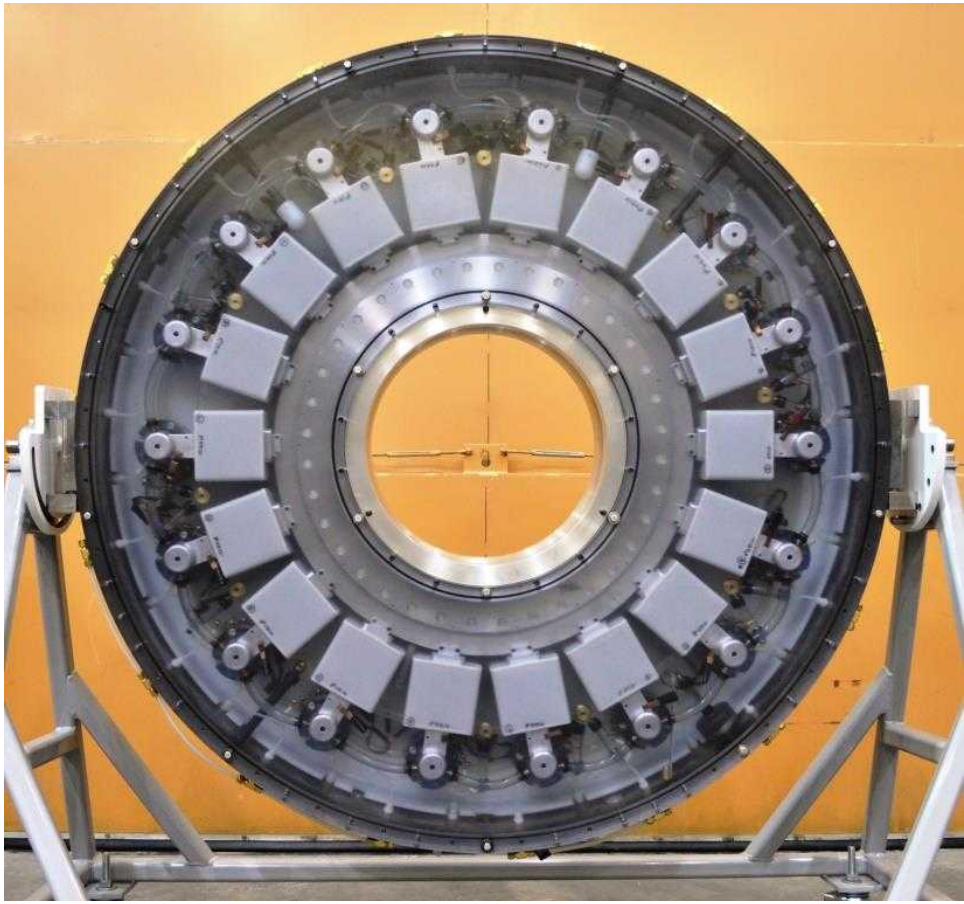
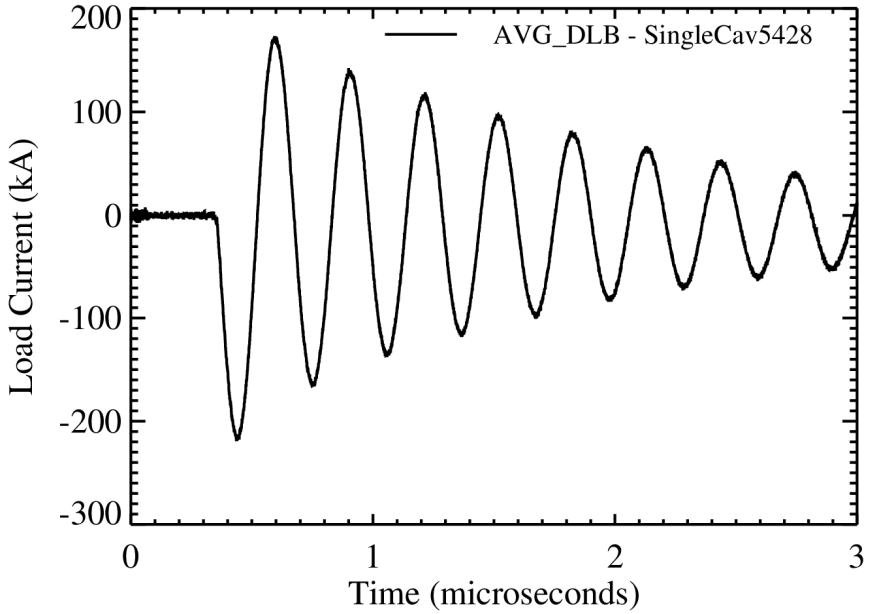
- Oil filled cavity
- Vacuum interface capable of operation in either polarity
- 18 parallel bricks
- 12-nF capacitors (also accommodates 20-nF)
- L-3 switches (though other switches can be used)
- 4 Metglas Cores (2 on each side)



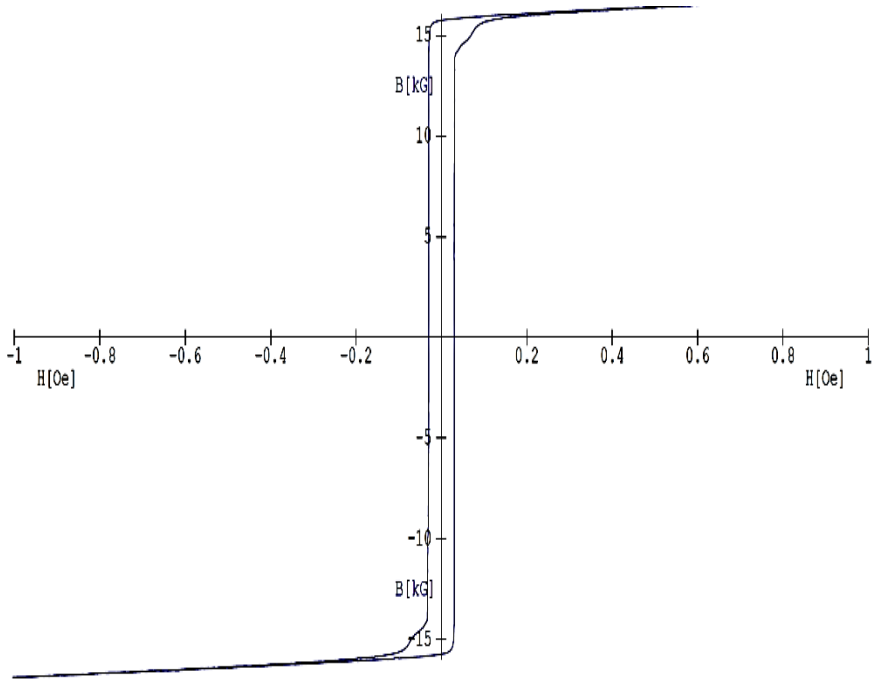
Short-circuit shots were used to develop accurate circuit model of the cavity

- Shots fired at +/- 50 kV charge
- Brick Inductance calculated from short circuit current oscillation period:
  - $L_{total} = \frac{(T/\pi)^2}{C}$ = 22.2 nH
  - L_{brick} = 189 nH
- Series Resistance was calculated from the decay in peak current
  - R=0.03 ohms
  - Rbrick = 0.54 ohms



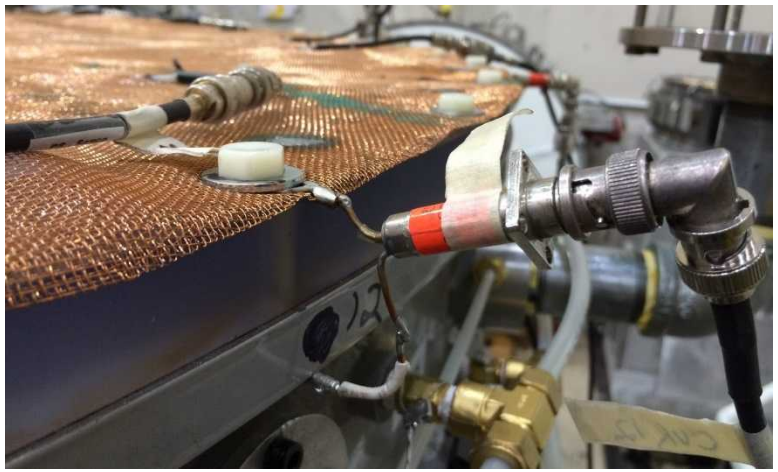
Metglas Core hysteresis is typically characterized at 60-Hz, not pulsed operation

- The cores in the 18-brick cavity were intentionally designed with higher V-sec than required for a standard output pulse with 100-kV charge. This was done to allow measurement of core loss when operating far from saturation vs close to saturation.
- Core Stats:
  - Four total cores per cavity with two on each side
  - 1” wide Metglas 2605CO
  - Predicted total V-sec = 20.5 mV-s



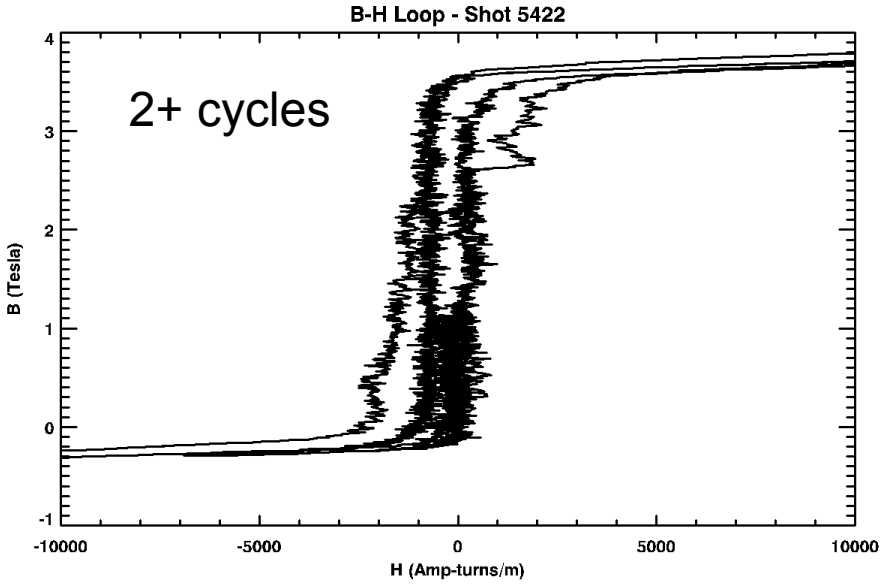
Pulsed Core Loss Measurement Configuration

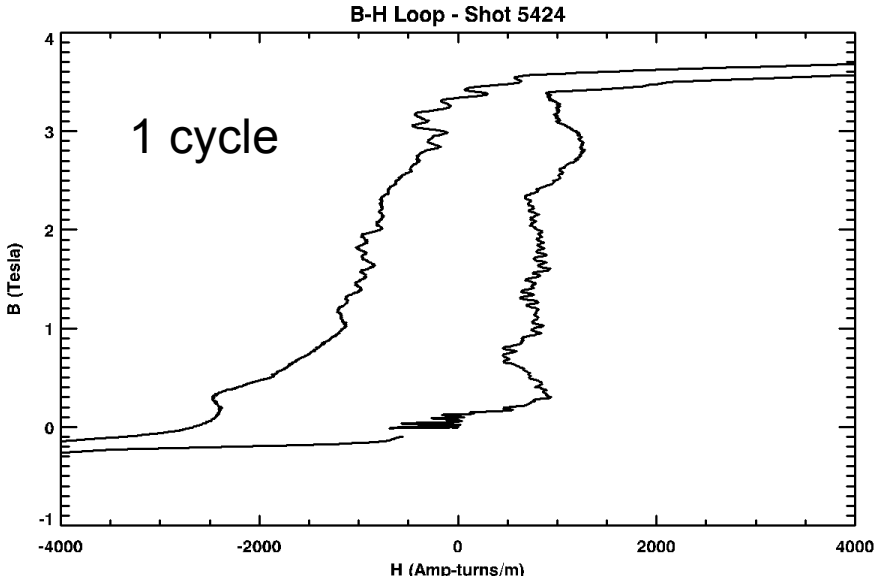
- Plastic side plate is installed on the 18-brick cavity with a copper screen over the top.
- Around the outer diameter, the plate is held in place with Nylon bolts
- 12 CVRs are installed around the perimeter across the insulator so that all of the current around the cavity case must pass thru the CVRs.

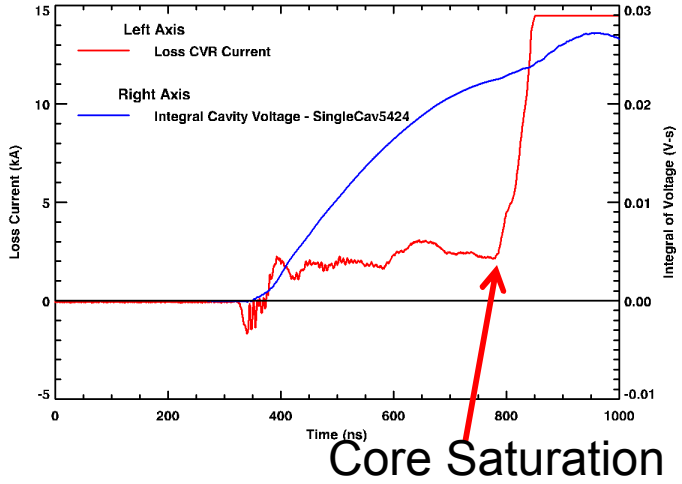


B-H Loop from open circuit shot

- Open circuit shots were fired by emptying the load resistor solution. Shots were fired at +/- 50 kV.
- The B-H loop was calculated from open circuit shots with loss current CVR measurement



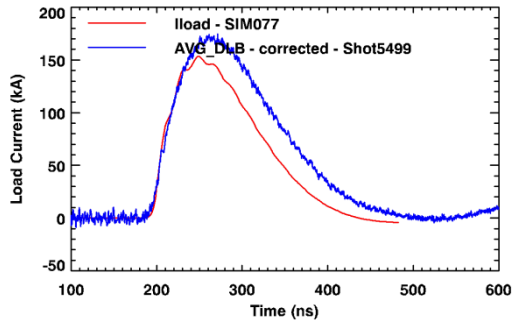


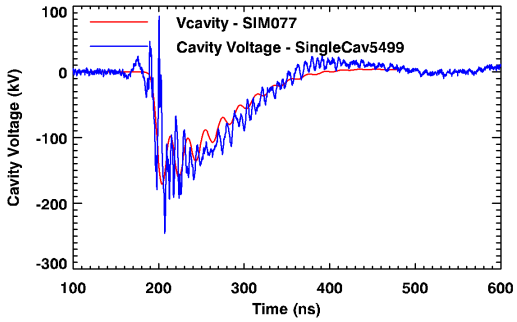


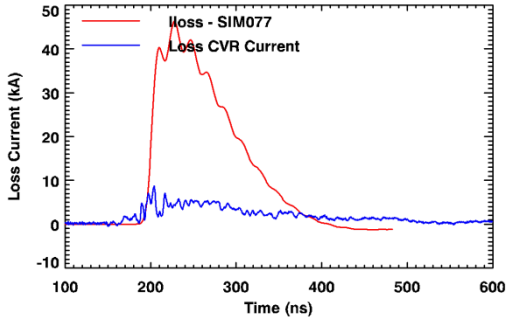
Core Saturation

Simulations from 2013 predicted lower output voltage and current

- In 2013, we presented simulations of the new LTD design based on previous LTD cavity experiments
- Some circuit values were intentionally conservative
- The experimental measurements show slightly higher output voltage and current than predictions
- Measured loss current is about 10x lower than predicted







Simulation
Data

Updated simulations match experimental measurements with various load conditions

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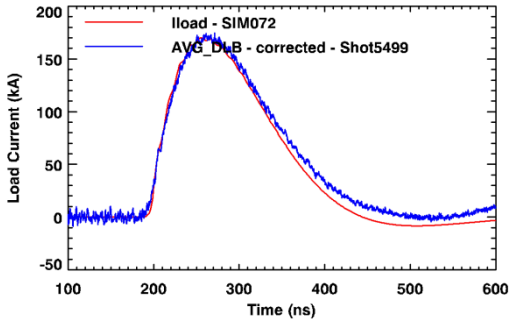
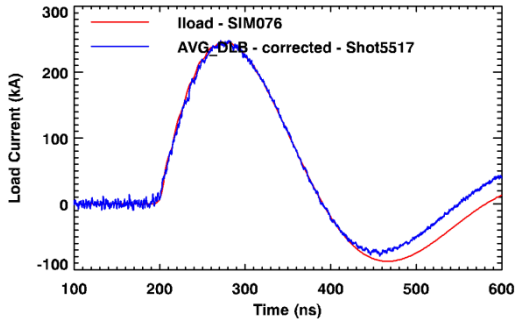
Simulation
Data

R=0.72 ohms

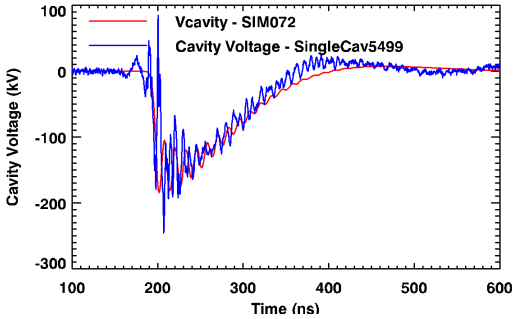
R=0.30 ohms

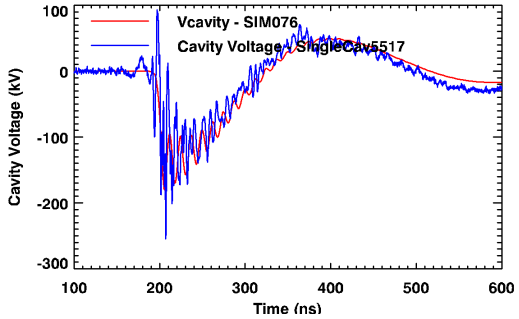
Load Current



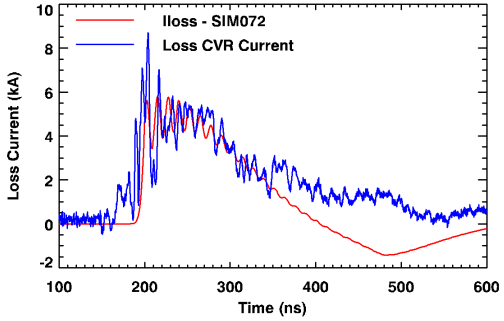


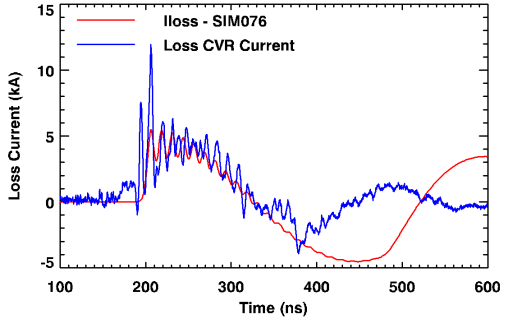
Cavity Voltage





Loss Current





Updated circuit model has higher inductance and lower loss

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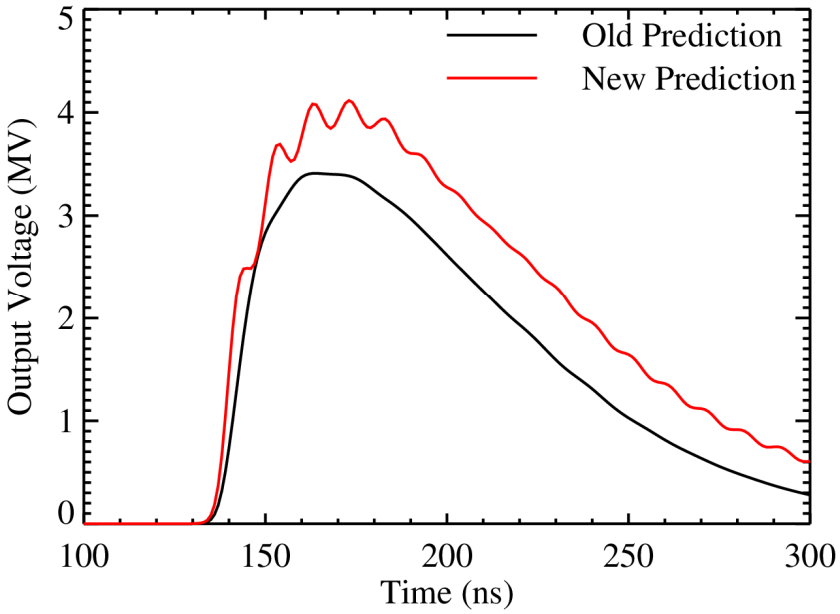
- New model has 20 nH higher inductance
  - Circuit has higher inductance than original model because we opted to use available switches instead of the lower inductance Kinetech switch which would reduce the brick inductance by 20-25 nH
- New model has almost 10x lower loss
  - The old model assumed higher core loss to allow for use of more lossy cores if the desired grade of Metglas was not available.
  - The old model assumed somewhat higher series switch resistance because at the time insufficient data was available for lower peak current operation.

The 32-cavity system is now projected to produce nearly 4-MV in negative polarity

- Circuit simulations of a 32-cavity system predict approximately 15% higher output voltage than previous predictions
- Options include:
  - Higher output than originally promised
  - Same output from fewer cavities (28 cavities)
  - Same output at lower charge voltage for increased reliability



Summary

- A new LTD based accelerator was presented in 2013:
  - Capable of generating up to 3.5 MV
  - Up to 2.5 MV in positive polarity without electron flow
  - Changing polarity is done with minimal maintenance
- A prototype cavity has been assembled and tested
- Based on the prototype cavity testing, the proposed 32-cavity LTD would be capable of:
  - 4.0 MV in negative polarity
  - The original 3.5 MV capability could be provided with only 28 series cavities.