OPERATING THE FIRST WATER-INSULATED MYKONOS II LTD VOLTAGE ADDER*

SAND2012-7126C

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LTD Technology is a New Paradigm in Accelerator Physics.

- The High Current Electronics Institute at Tomsk (HCEI), Russia, Sandia National Laboratory, USA, and the International Technologies for High Pulsed Power (ITHPP), France, are the leaders toward the development of a new class of compact, high current, high voltage, very fast (70-100-ns) pulse generators based on the LTD (Linear Transformer Driver) technology.

- The salient feature of the new technology is switching and inductively adding the pulses at low voltage straight out of the capacitors through low inductance transfer and ferromagnetic core isolation (basic unit = stage or LTD cavity).

- We can inductively add stages (cavities) in series in a voltage adder configuration (like, HERMES III, RITS-6 e.t.c.) to get Multi-Megavolt outputs.

- We can add in parallel many voltage adders to get both Multi-Megavolts and Multi-Mega-amps.

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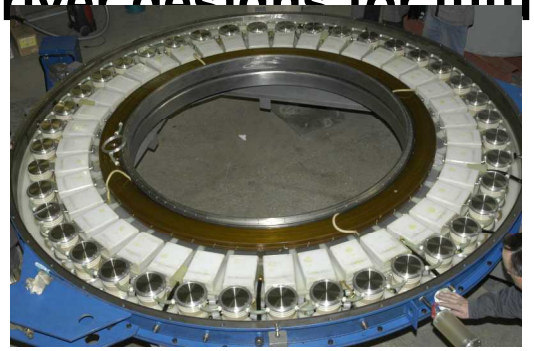
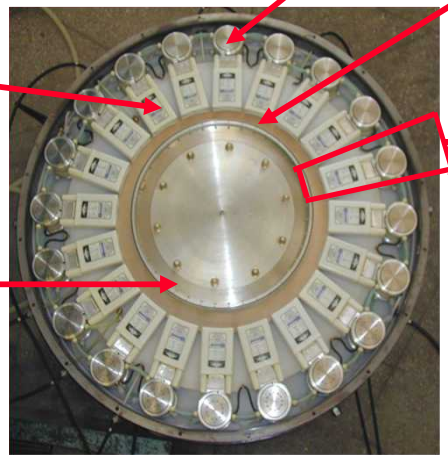
Presentation Outline.

- Introduction
  - The LTD cavity.
  - 0.5 MA LTD I and LTD II, a success story.
  - Induction accelerator with LTD cavities.

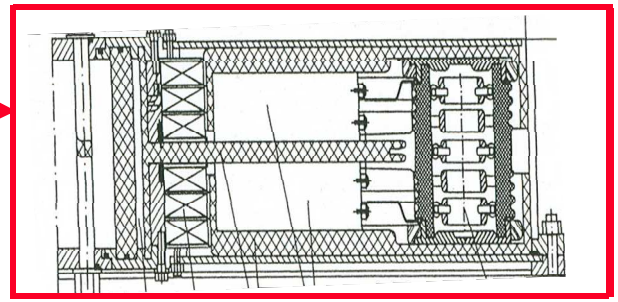
- Experiments with 1-MA LTD cavities
  - Single cavity.
  - Five cavity vacuum insulated voltage adder.
  - Why to use voltage adders with water insulation.
  - Two cavity, MYKONOS II, water insulated voltage adder.
  - Conceptual high current LTD driver designs for future consideration.
- Summary
- Future plans



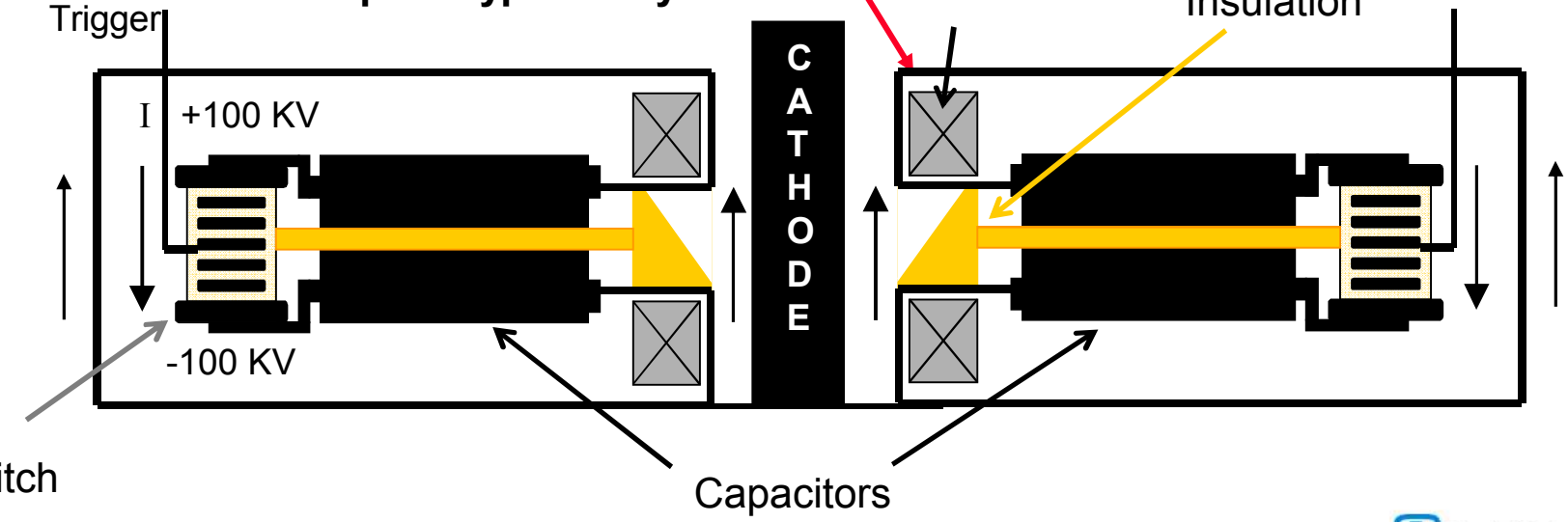
The fast LTD cavity is an induction accelerator cavity which encloses the pulse producing circuits ("bricks").



0.5-MA prototype cavity



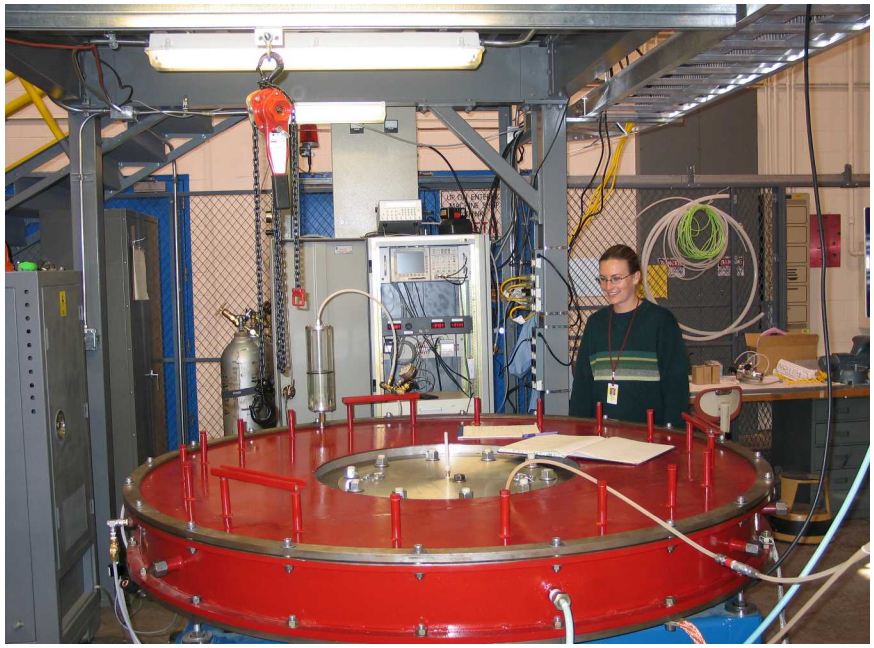
Brick side section



LTD I and LTD II cavities. A success story

LTD I LTDII Performance Summary

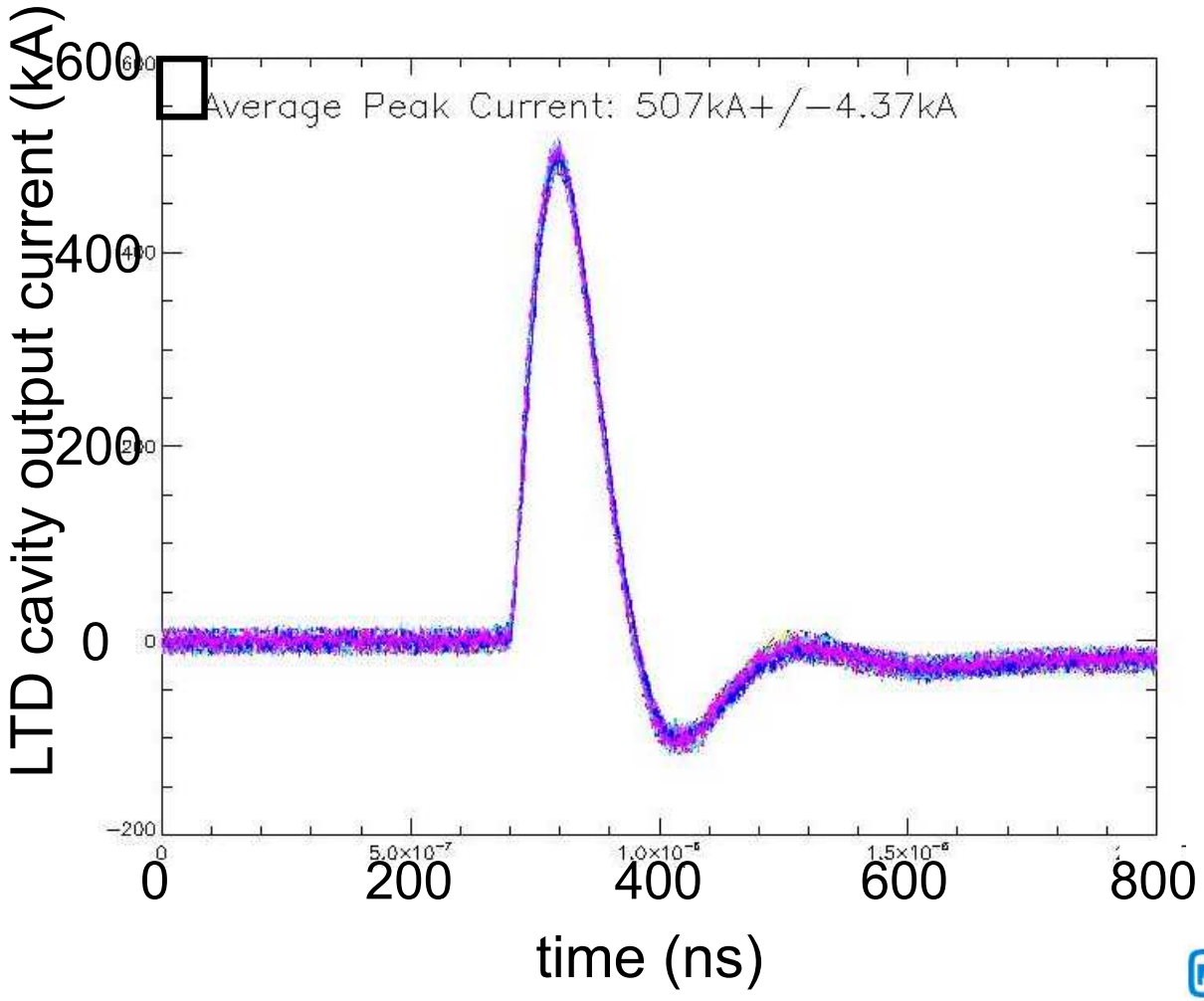
We have fired the prototype LTD I cavity for over 13,000 shots in rep-rated mode at 85 kV.



The first 0.5-MA LTD I

Data confirm that LTD's are very reliable.

Overlay of 200 consecutive Shots



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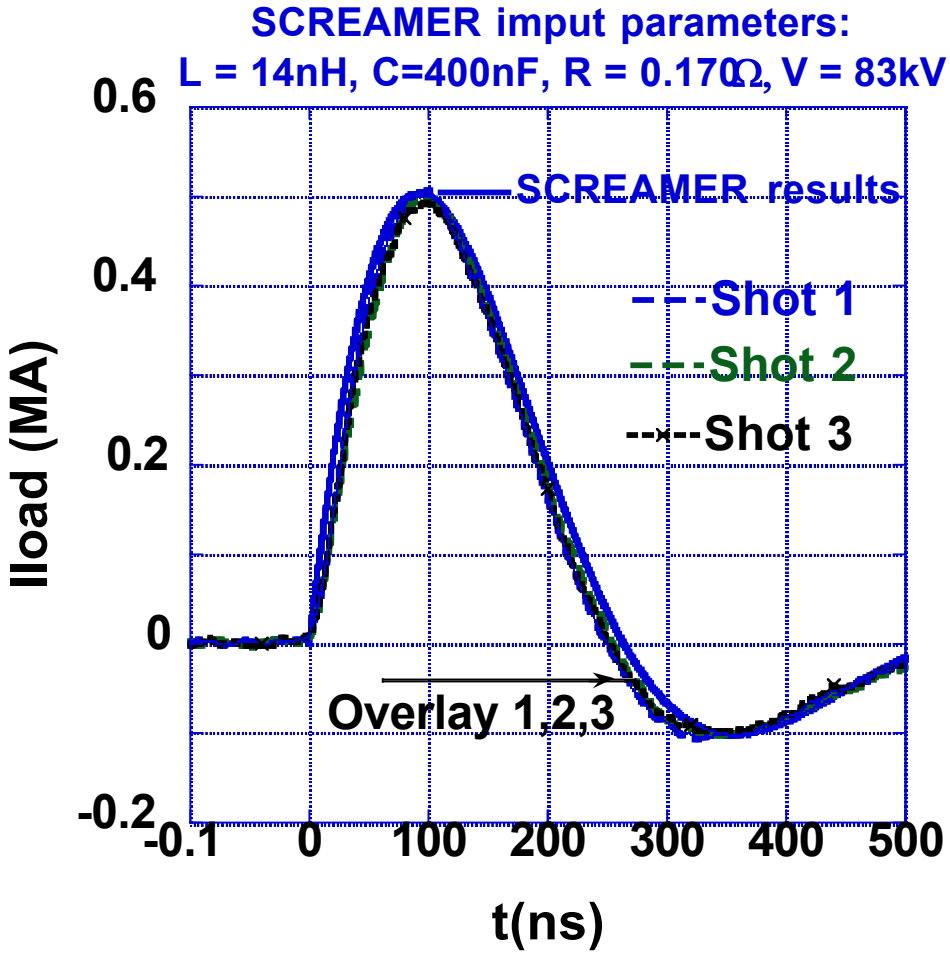
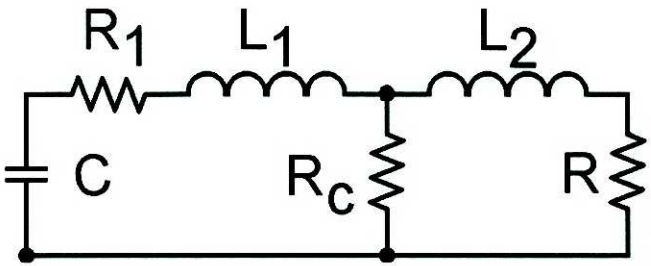
The LTD I exceeded 13,000 shots at 85-kV in a rep-rated mode at 0.034 to 0.097 Hz.

- Cavity performance very reproducible.
- Output wave forms follow very closely code simulations.

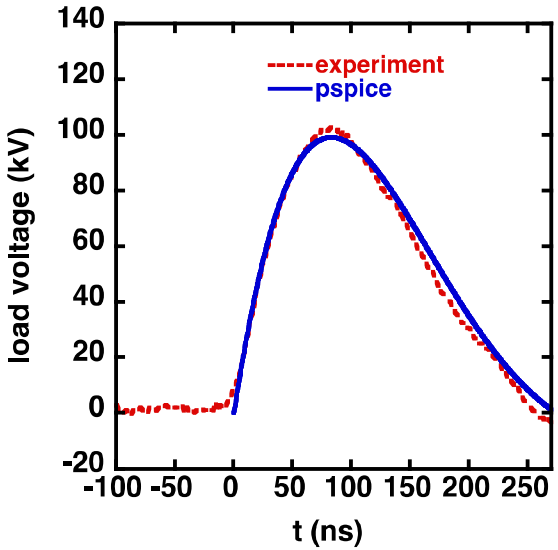


We have fired 10,000 shots with the second LTD II cavity in rep-rated mode and at +/-100 kV charging.

- We fired 200,000 switch shots with no pre-fires.
- Results are in good agreement with simulations.



C = 400nF
R_1 = 0.033Ω
L_1 = 12nF
R_C = 1.3 Ω
R = 0.2 Ω



We have fired LTD I and LTD II cavities for over 23,000 shots (= 460,000 switch firings) in rep-rated mode at 85-100kV.

cavity performance:

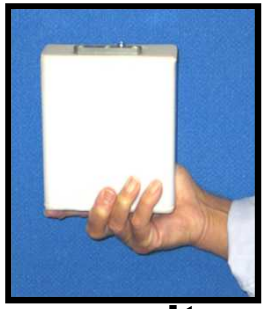
- Switch closure jitter: 1.2-2 ns (1s)
- Switch closure time: 80-100ns
- Pulse rise time: 55.5 ± 1.5ns
- FWHM: 132 ±2.5ns
- Voltage and current reproducibility = 0.3% (1s)
- Peak power = 0.042 - 0.05TW
- Output energy = 4-7 kJ
- Electrical efficiency = 70%
- No pre-fires at 350-460 kPa
- Maximum rep-rate = 0.097Hz (IFE requires 0.1Hz)

M. G. Mazarakis, W. A. Fowler, A. A. Kim *et al.,* Phys.Rev. ST Accelerators& Beams, 12, 050401 (2009)

The 1-MA LTD Cavity

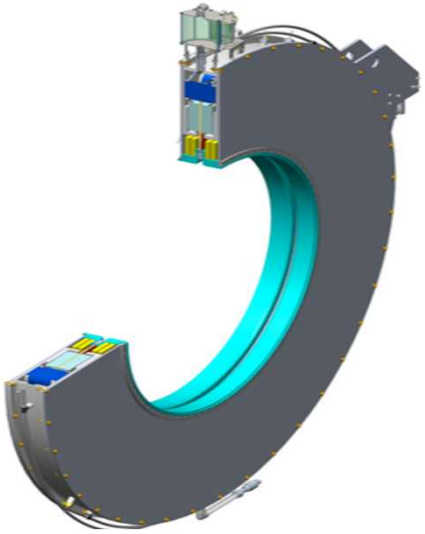
Only 3 basic components

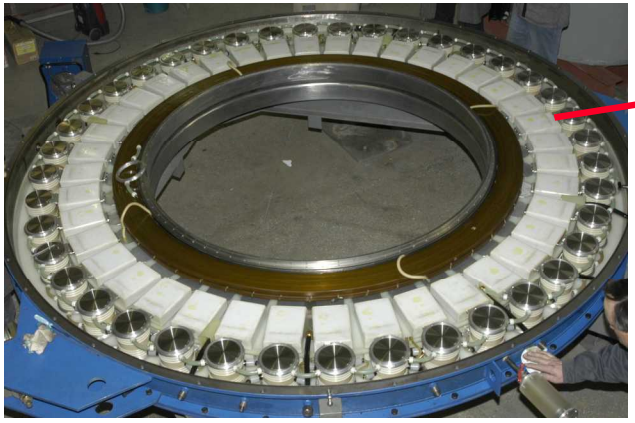
switch



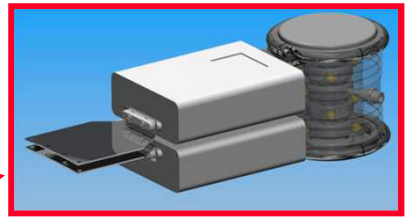
capacitor

ferromagnetic core





brick



40 bricks
40 nF caps
L= 6 nH
C= 800 nF
Ropt. Load = 0.108 Ω

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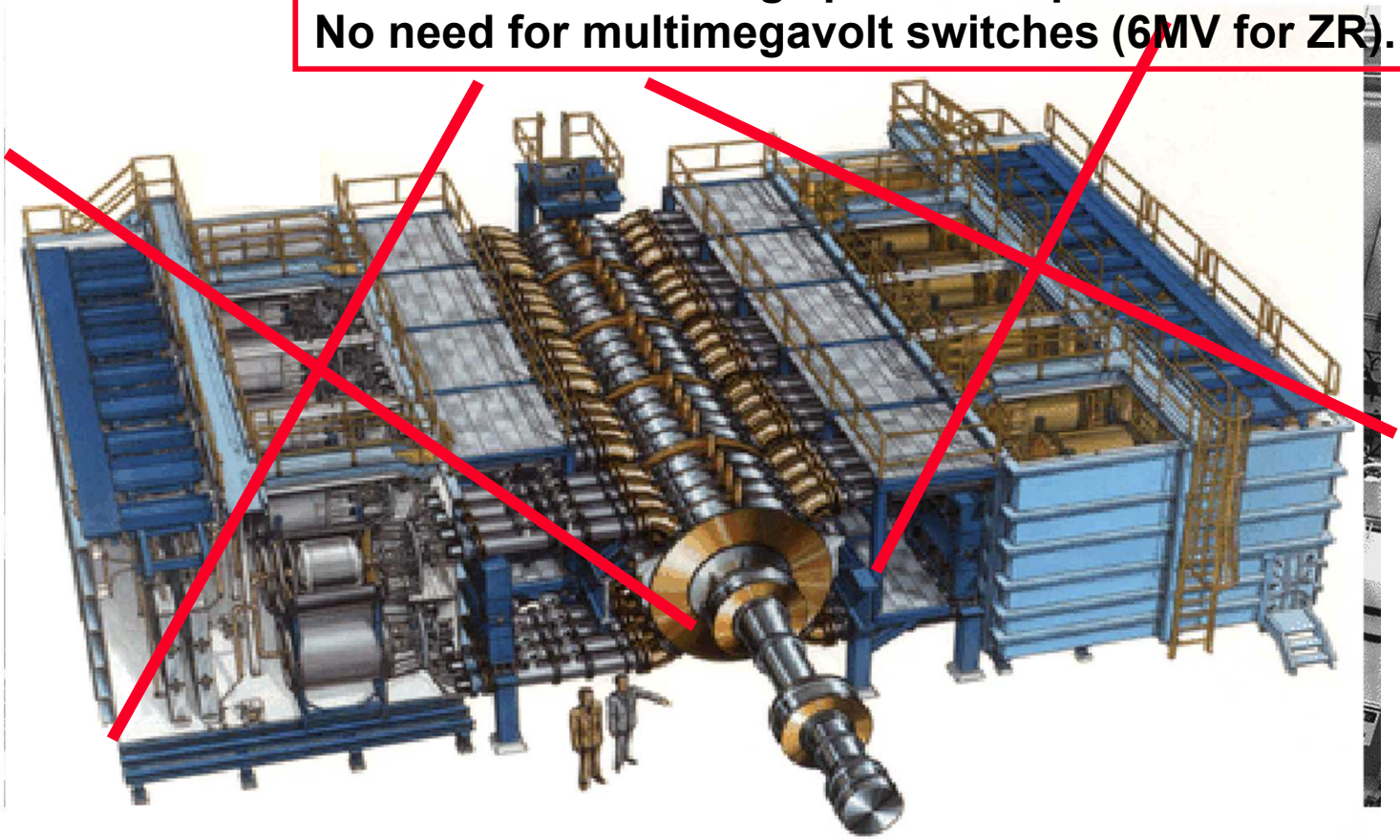
A 1-MA, 20-MV LTD voltage adder will look like the HERMES-III center section. However, it would be longer.

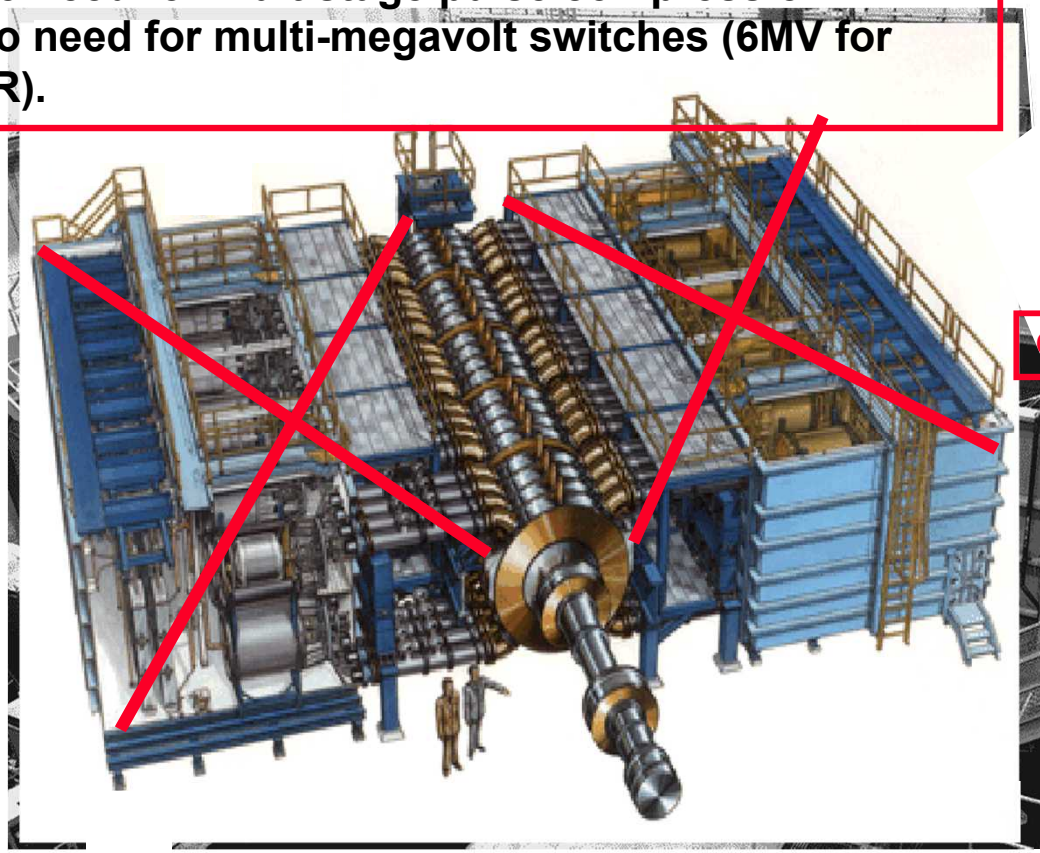
LTD drivers are compact.
No need for multistage pulse compression.
No need for multimegavolt switches (6MV for ZR).



HERMES III

A 1-MA, 20-MV LTD voltage adder will look like the HERMES-III center section but with smaller diameter.

LTD drivers are very compact.
No need for multistage pulse compression.
No need for multi-megavolt switches (6MV for ZR).



LTD

Only the cavities will remain

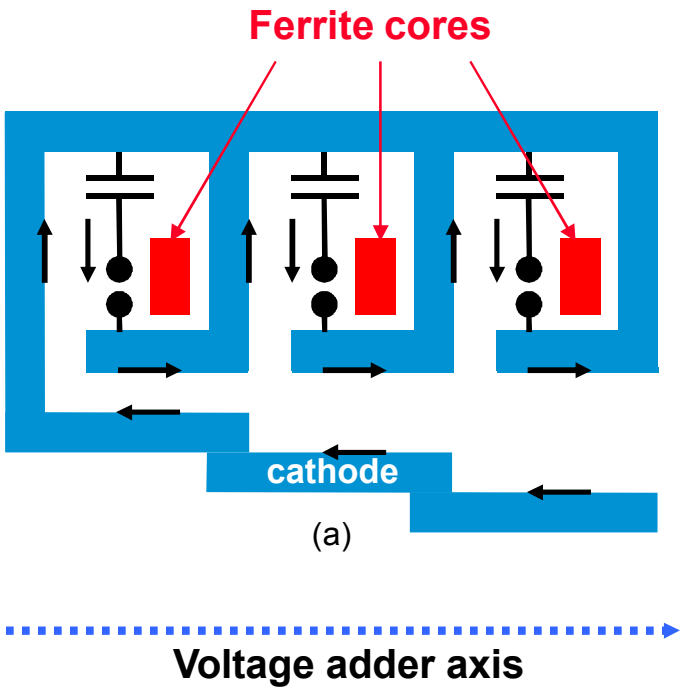
HERMES III

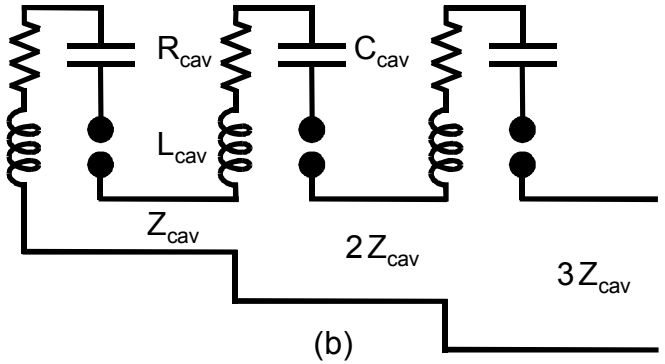
An LTD Voltage Adder is an adder that connects in series a number of inductively isolated LTD cavities.

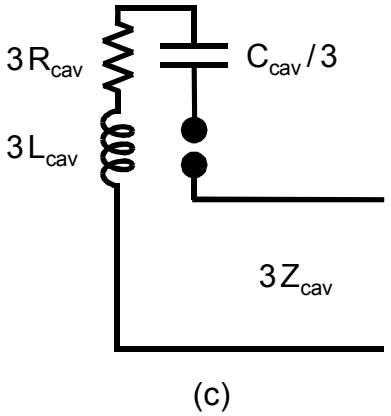
LTD five 1-MA cavity Voltage Adder Vacuum Insulated

A. A. Kim, M. G. Mazarakis, *et. al.*,
Phys. Rev.ST Accelerators and Beams 12, 050402 (2009)

To first order, an n-cavity LTD module can be modeled as a simple RLC circuit.







M. G. Mazarakis *et al*. "A Compact, High-Voltage E-Beam Pulser," 12th IEEE Pulsed Power Conference, Monterey, California, July 1999.
Pulsed Power Conference Proceedings p. 412

Why water insulation.

Advantages of water insulated voltage adders

- Current flows on the surface of the conductors.
- No sheath current erosion and resulting pulse shortening.
- Can be terminated with high impedance loads without losing ~1/3 of the total current on the walls.
- No wall erosion.
- Lengthen transit time from cavity to cavity by a factor of 9.
- The later is very important for output pulse shaping by staggering cavity trigger.

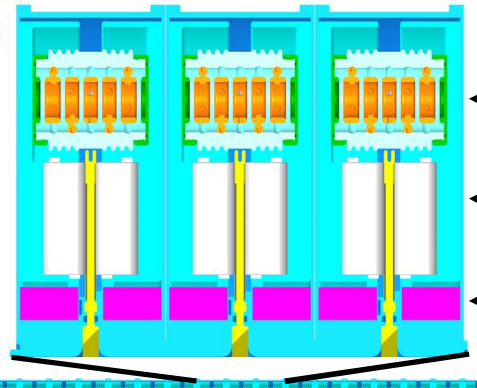
Disadvantages

- High voltage water vacuum interfaces for a long 6MV voltage adder.
- Air bubbles in an enclosed system.
- Metal corrosion.
- Extremely high forces to compress cavities water tight (60,000ib).
- Larger weight.
- Water filtering de-ionizing, re-circulating, and de-bubbling system.
- Lengthier service and maintenance.

We feel that the advantages may outweigh the disadvantages. Our goal is to test this assumption.

Sixty LTD cavities connected in series in a voltage adder configuration.

expanded view of 3 1-MA LTD cavities

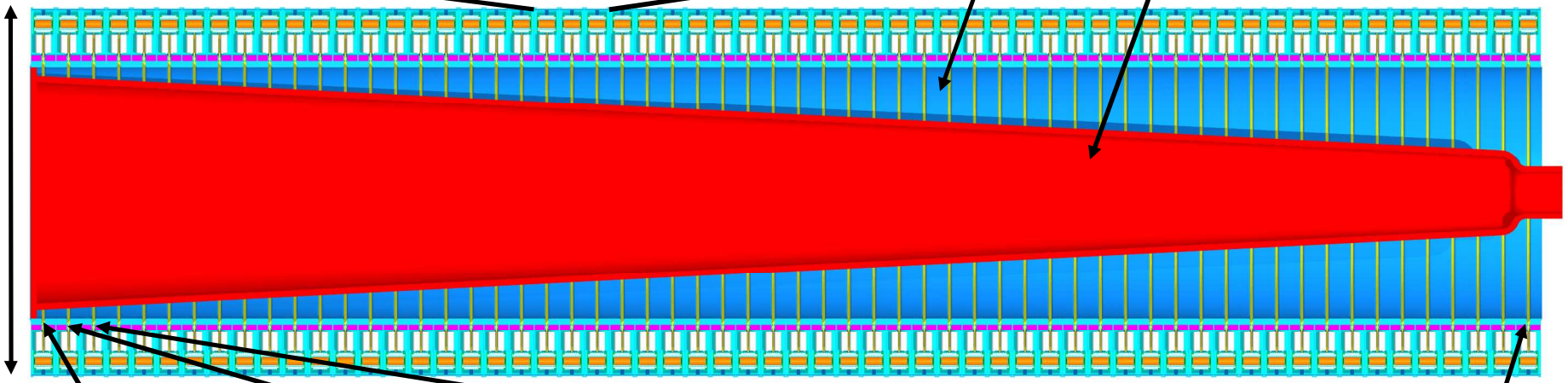


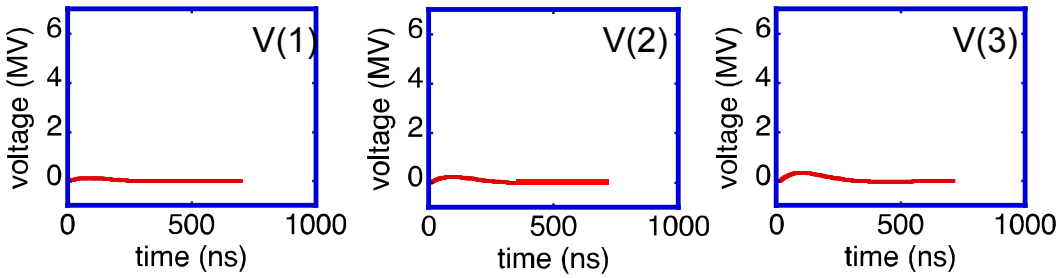
Deionized water insulator

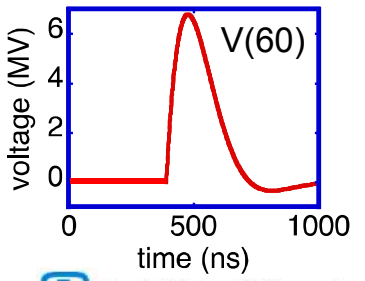
central conical conductor

energy efficiency = 70% wall plug to output

3 m







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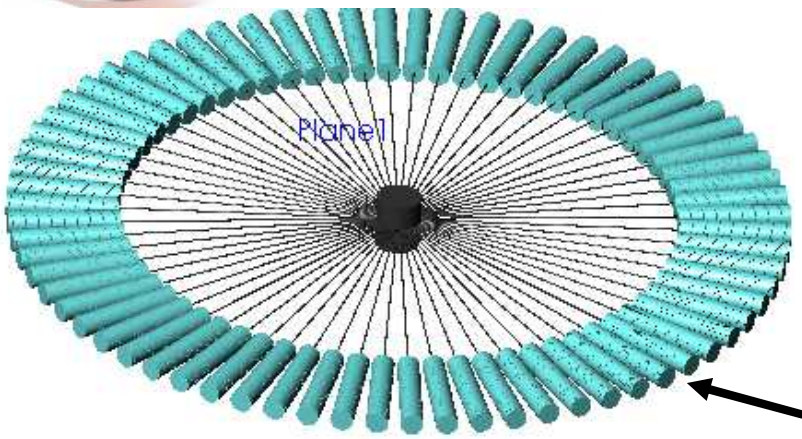
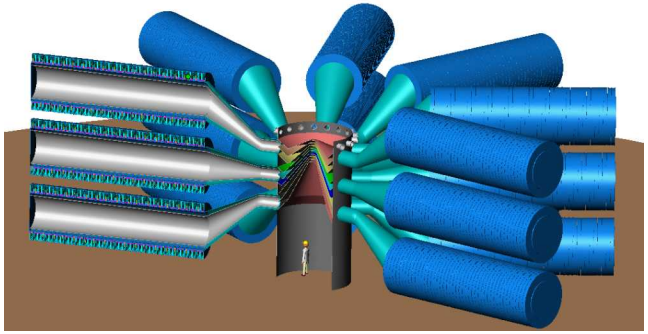
Conceptual designs of z-pinch drivers with multiple 1-MV, 100-ns LTD voltage adders connected in parallel.

With future very low inductance switches and high density capacitors the designs could shrink dramatically.

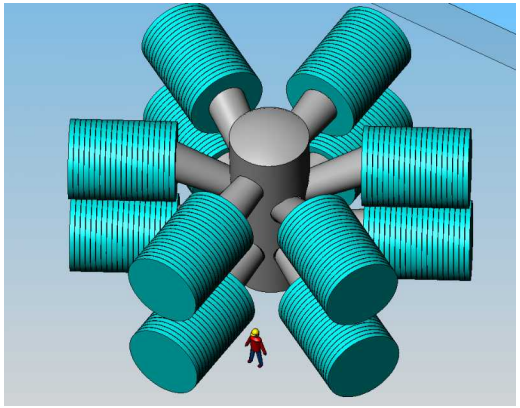


0.5 Petawatt driver

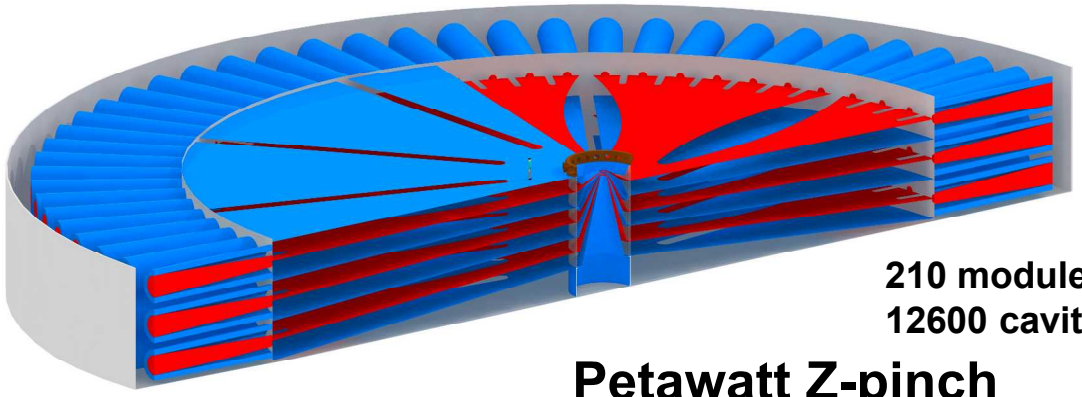
1-MA, 7-MV voltage adder



ZR equivalent



Saturn equivalent



210 modules
12600 cavities

Petawatt Z-pinch driver

W. A. Stygar *et al.*, Phys.Rev. ST Accelerators& Beams, 10, 030401 (2007)

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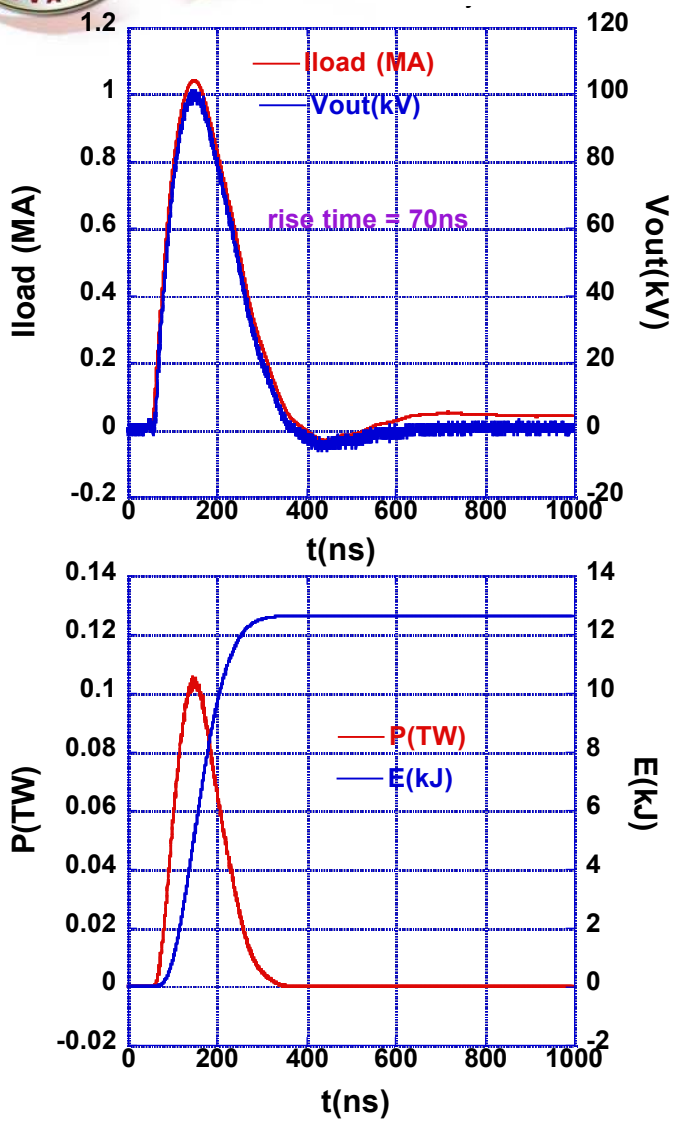
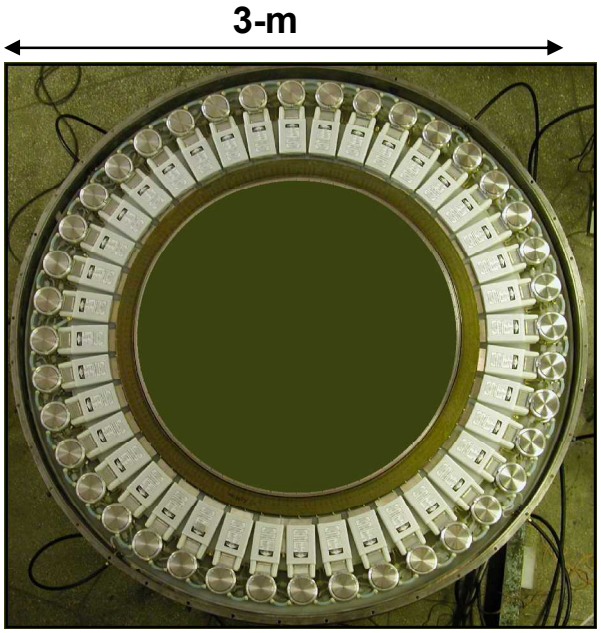
Experimental Results with the Original unmodified unmodified cavities

- **Vacuum Insulated 1-MA LTD Voltage Adder**

The 1-MA, 100-GW, LTD cavity performed as predicted by simulations and analytical calculations.





1-MA, 100-GW, 70ns LTD cavity
(top flange removed)

80, 40-nF caps ,

40 switches, ±100 kV

0.1 Ohm load 0.1TW

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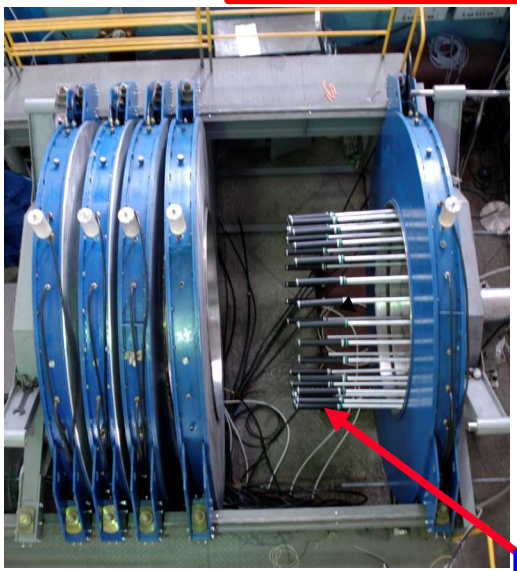
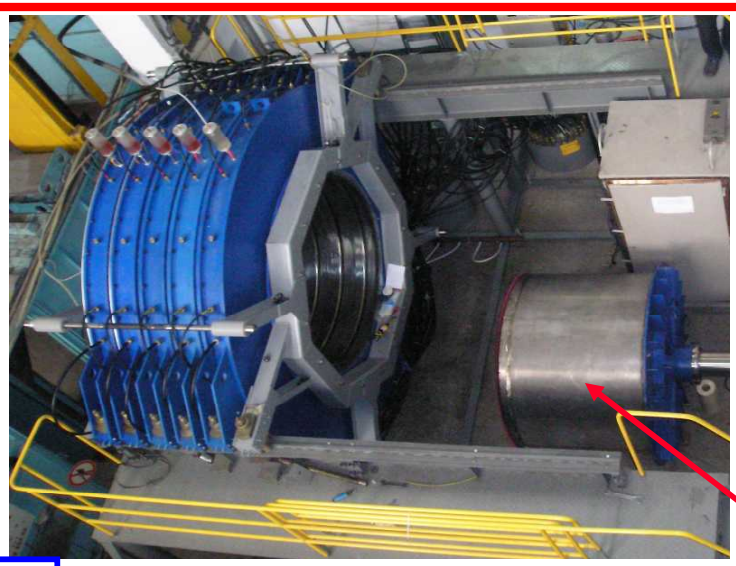
A five cavity 1-MA LTD voltage adder was tested with resistive and vacuum diode loads.

Experiments performed here at the HCEI under the direction of A. A. Kim.



resistors

Resistive load Experiments.



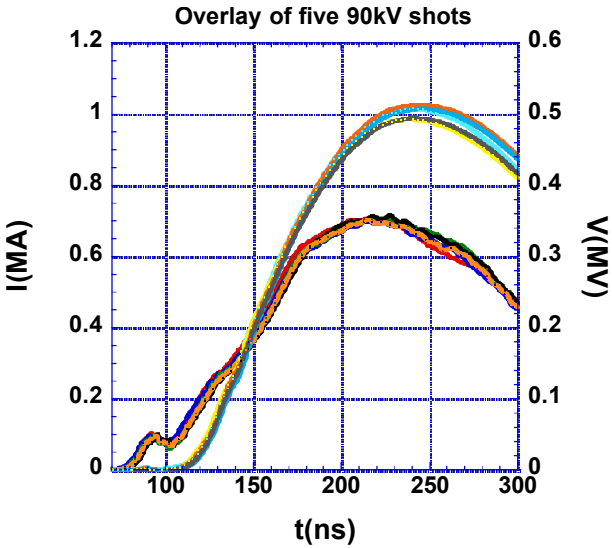
cathode electrode

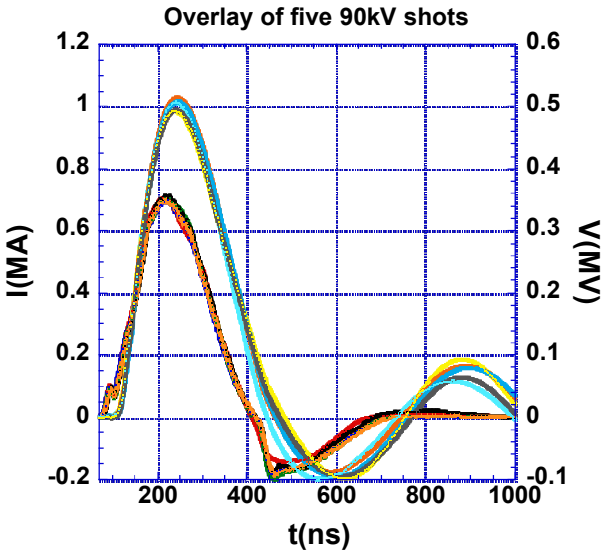
Vacuum diode load experiments.

A. A. Kim, M. G. Mazarakis *et al.*, Phys. Rev.ST Accelerators and Beams 12, 050402 (2009)

M. G. Mazarakis, A. A. Kim *et al.*, IEEE Trans. Plasma Sci. Vol. 38, NO. 4 2010

We have conducted 5-cavity LTD vacuum insulated voltage adder experiments.





A. A. Kim, M. G. Mazarakis, *et al*., Phys. Rev. ST Accelerators and Beams 12, 050402 (2009)

Work performed at the HCEI

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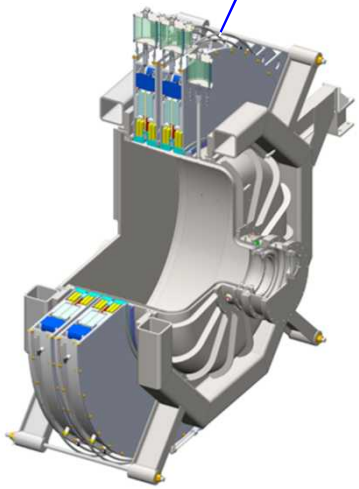
Experimental Results with the Original unmodified unmodified cavities

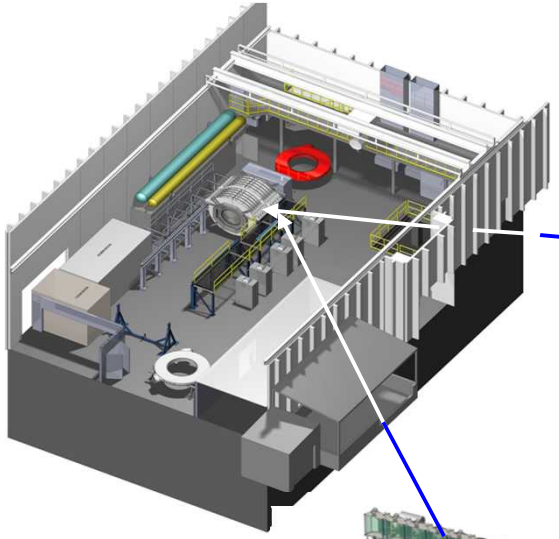
- **Water Insulated Mykonos II, 2 cavity 1-MA LTD Voltage Adder**

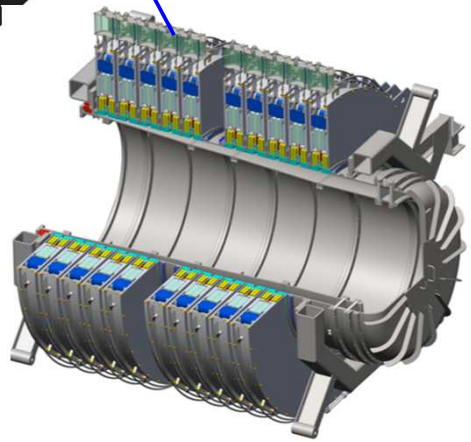
The MYKONOS laboratory is complete and the first two LTD cavity voltage adder is undergoing testing with water.

Sandia MYKONOS II, June 2012



MYKONOS X Laboratory)





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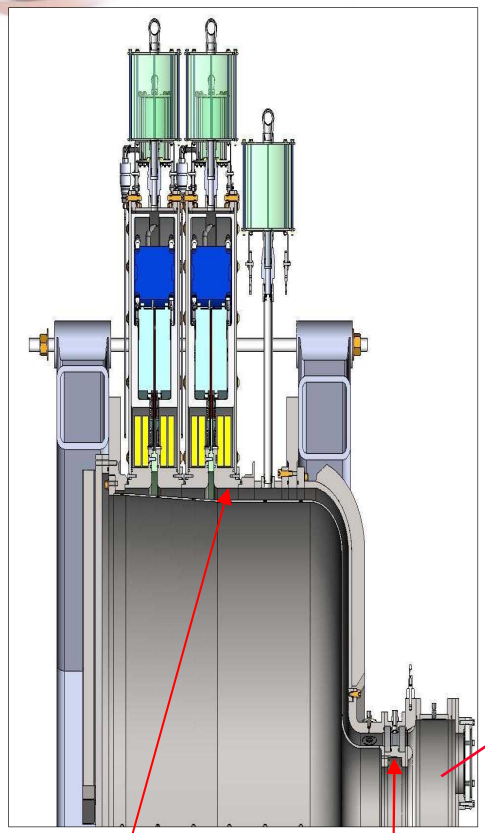
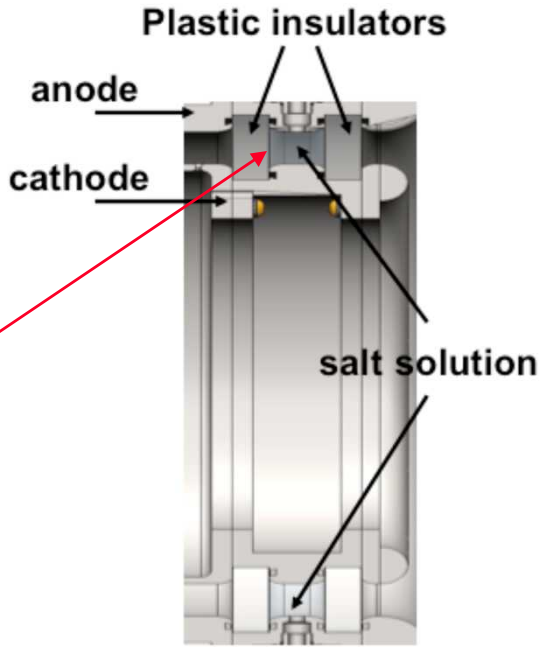
The two LTD cavity 1-MA 200-kV voltage adder

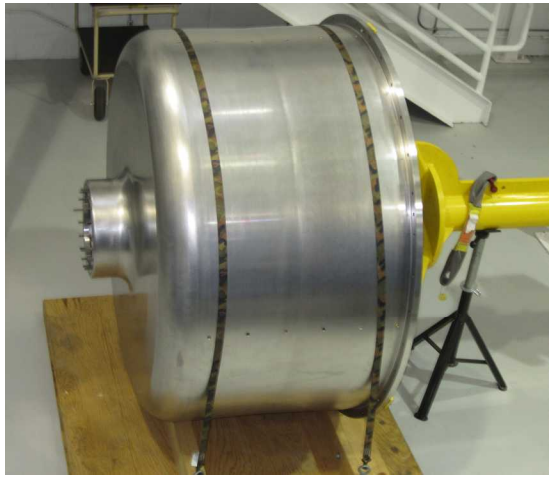


Two LTD cavity voltage adder



radial liquid resistive load

MYKONOS II Components

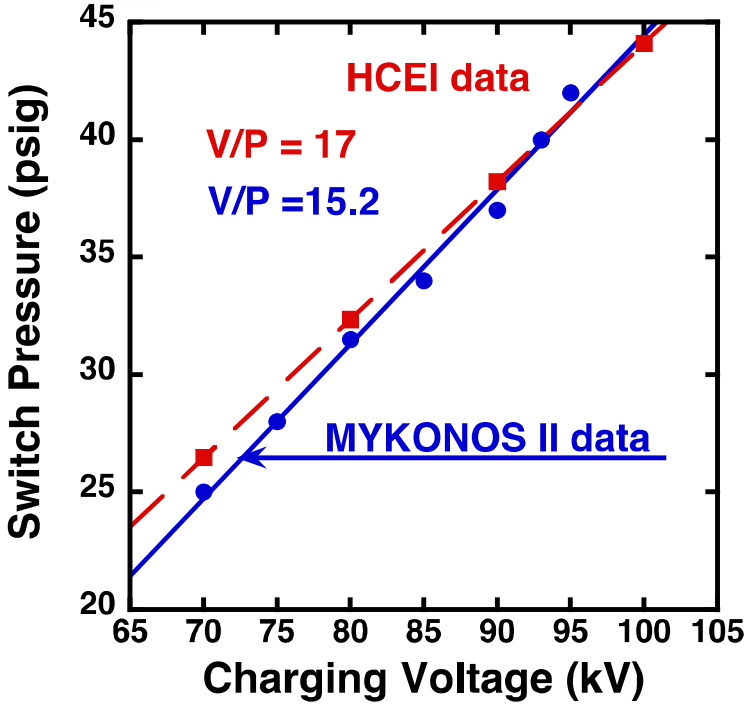


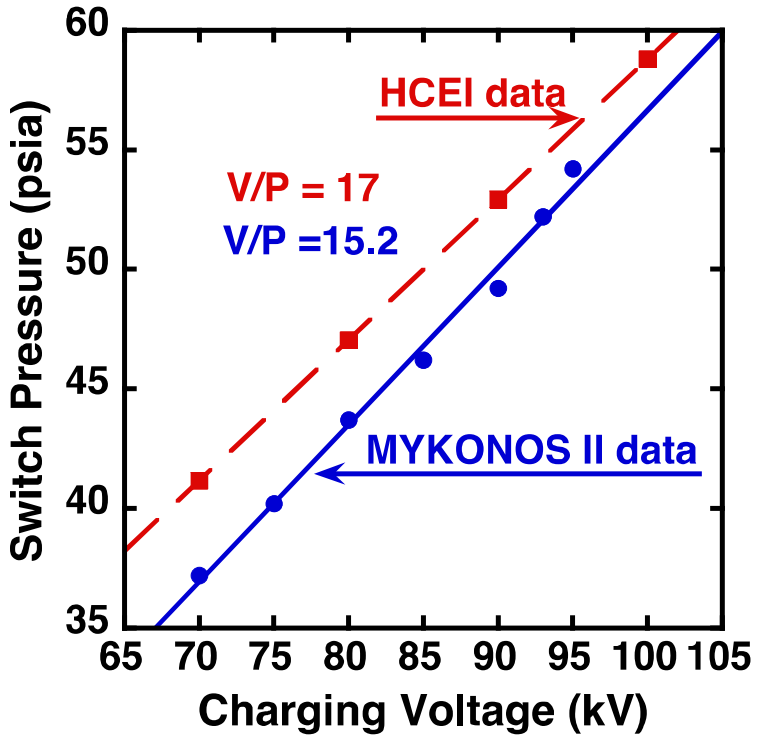
MYKONOS II
Cathode stock

Draining the cavity from oil

Mykonos II anode
cylinder

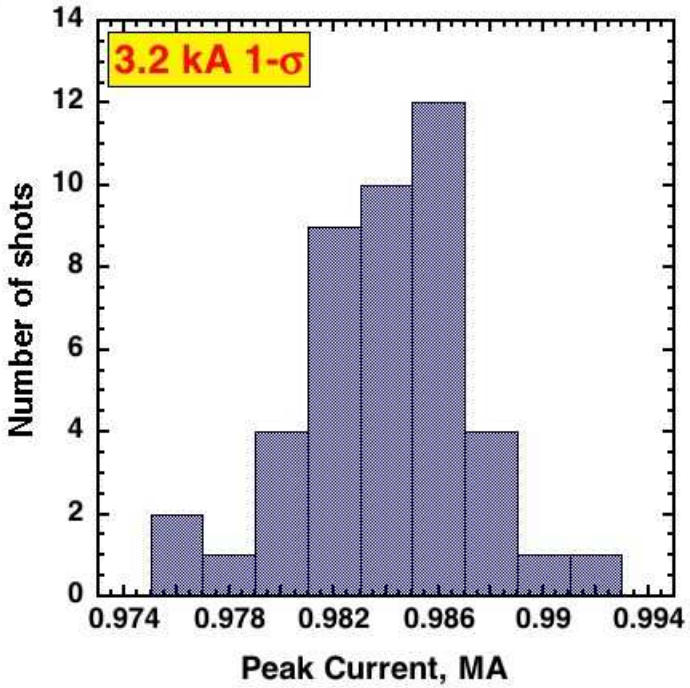
MYKONOS II Switch Conditioning Results Close to those of HCEI

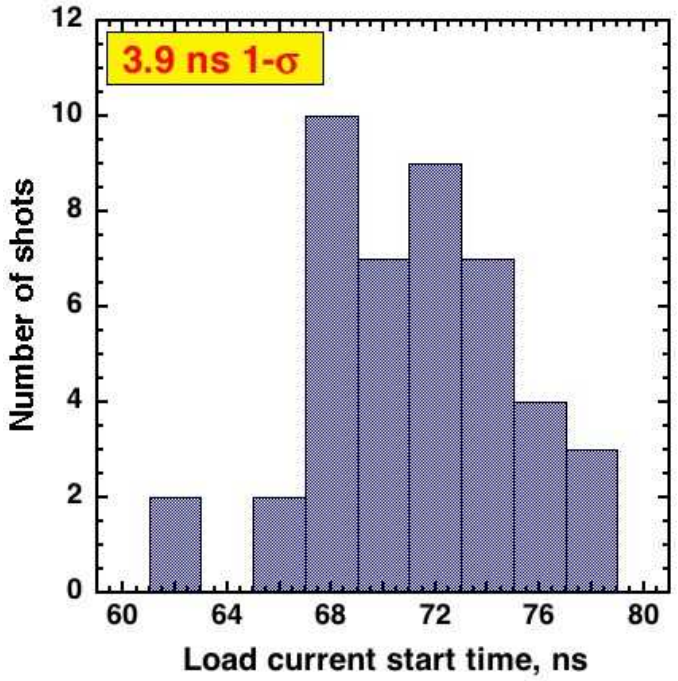




$\Delta p_{atmosphere}$ (Tomsk- Albuquerque) = 2.3 psi

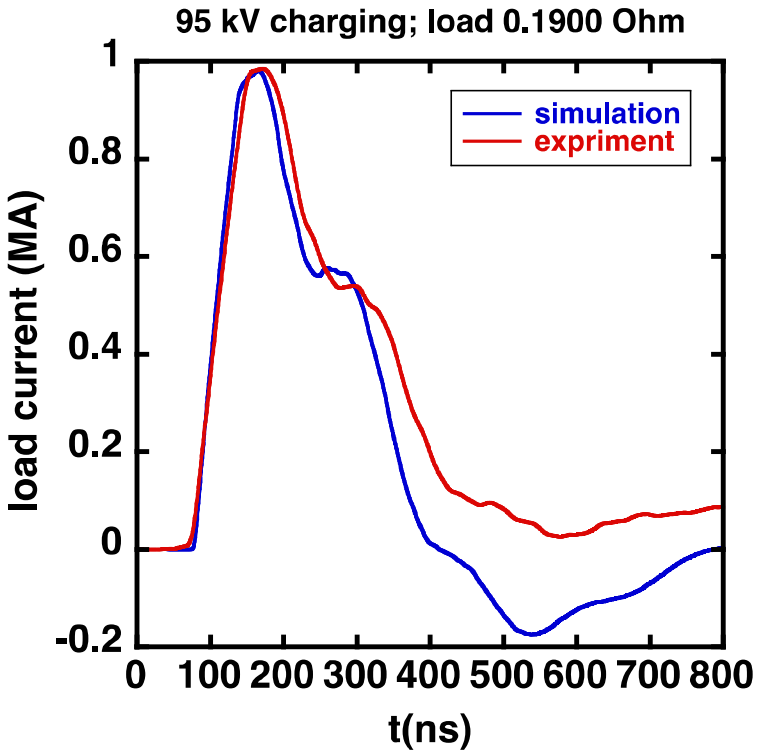
At 95 kV the switch pressure was not yet optimized; however the run time and peak current variation are reasonable.





Sample of 60 repetitive shots (3 shots/minute) results.

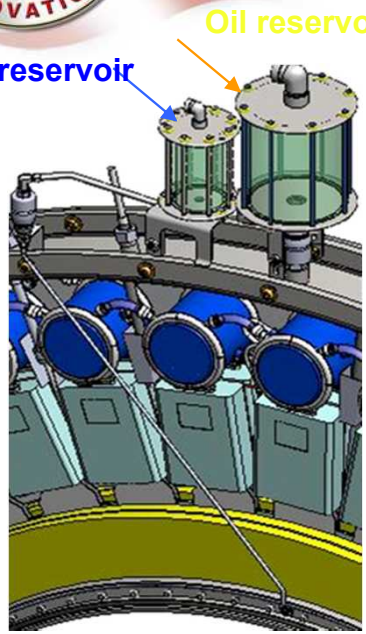
Comparison of Screamer circuit model simulations with Mykonos II Results



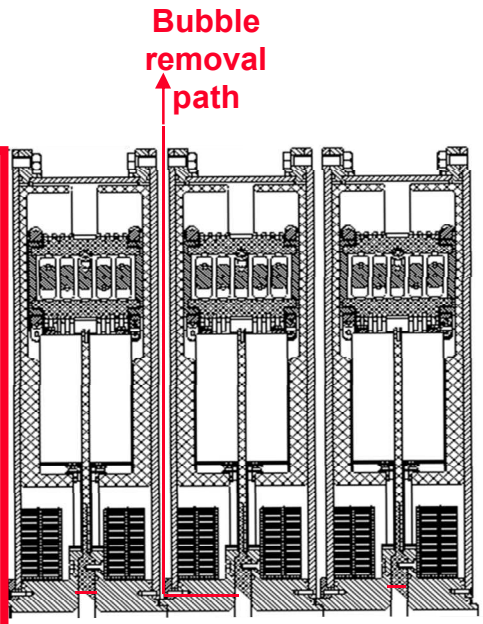
The assumed load impedance and inductance needs further adjustment.

Mykonos II cavity and Voltage Adder modifications.

The HCEI 1-MA LTD built cavities are being modified to operate in a de-ionized water environment

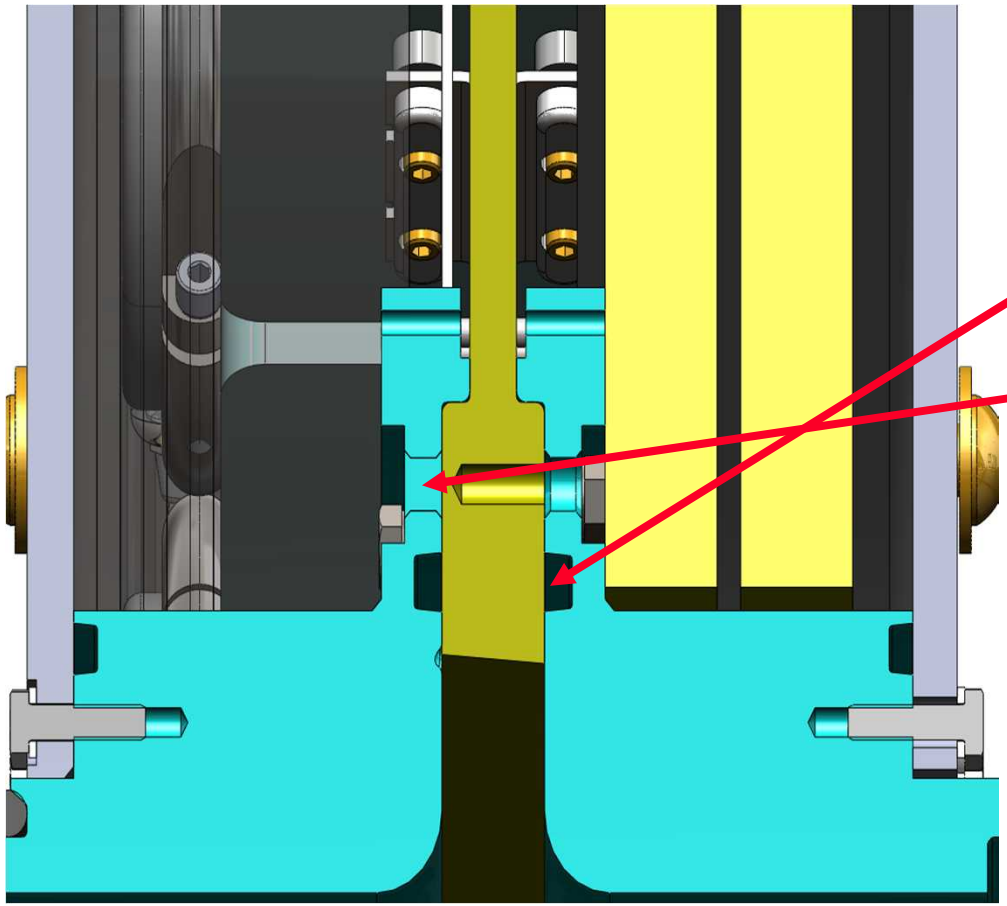


1. Passivate stainless steel surfaces
2. Provide bubble removal paths from the voltage adder interior
3. Install de-ionizing, de-bubbling, and re-circulating system,
4. Modify the cavity A-K electrodes. Fill existing bolt-holes and replace them with new ones on a perfect circumference. Make new " O" ring grooves to shield water from sipping into the cavity.



Other LTD cavity modifications Continue

4. Modify the cavity A-K electrodes. Fill existing bolt-holes and replace them with new ones on a perfect circumference. Make new “ O” ring grooves to shield water from sipping into the cavity.



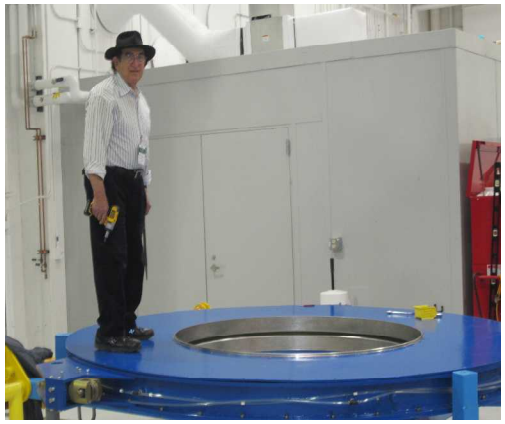
Larger O ring grooves.

Fill old bolt-holes.

Drill new bolt-holes on a perfect Circumference.

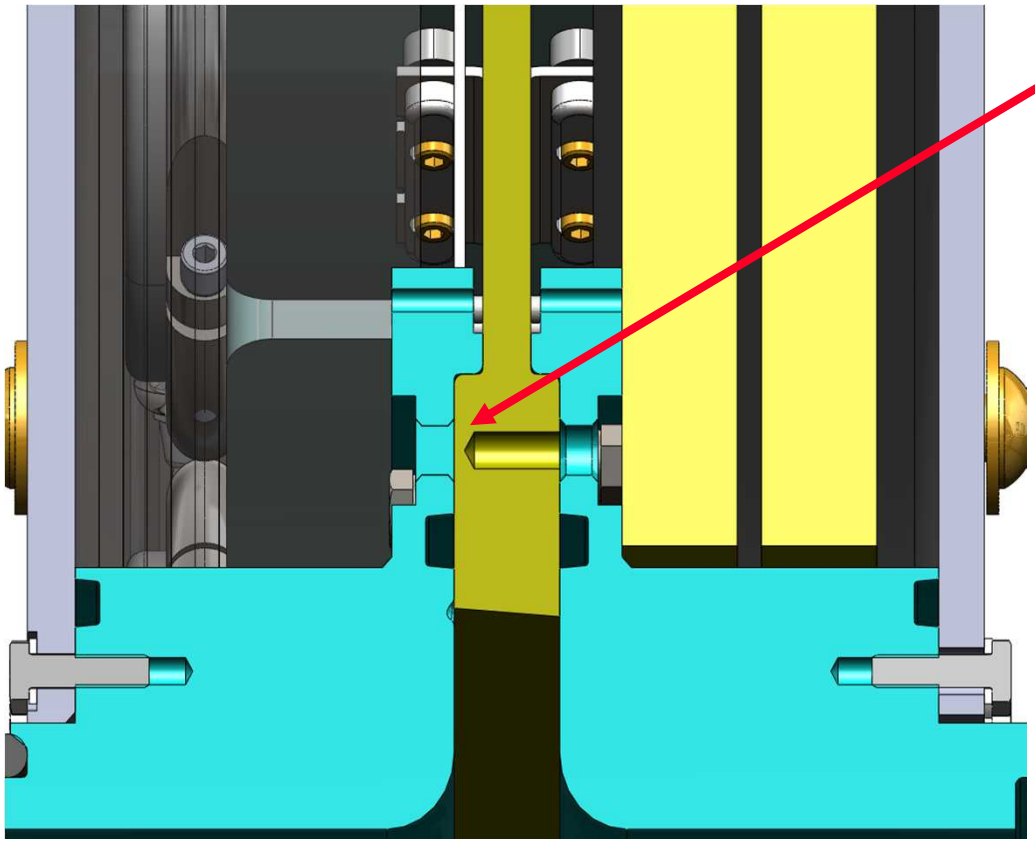
Other 1-MA LTD Cavity Modifications

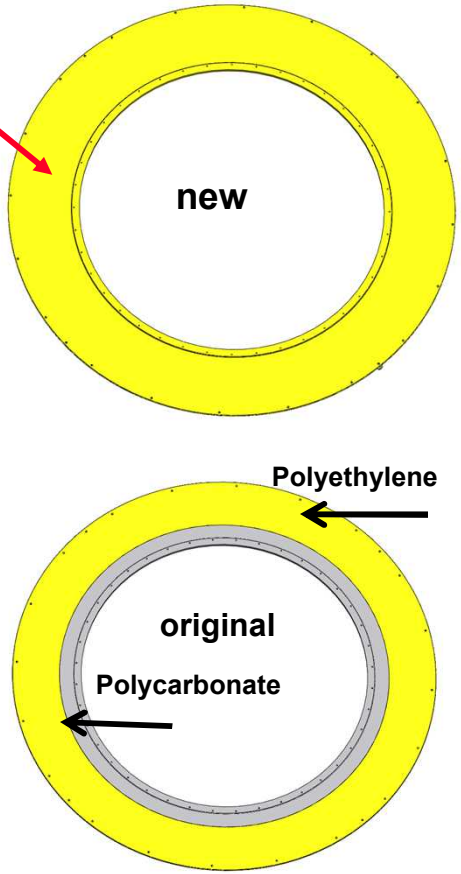
5. Disassemble and modify the HCEI switches and replace the Legris gas feed-throughs with Swageloks.
6. Replace the polyethylene insulators at the top and bottom of the cavities with polyurethane ones.
7. Use the thickest available Tygon tubing to build the charge and trigger resistors.
8. Install continuous oil recirculation and dual filtration system (< 200p/cm$^{3)}$.
9. Manufacture a steel thicker top cover with azimuthal slots.



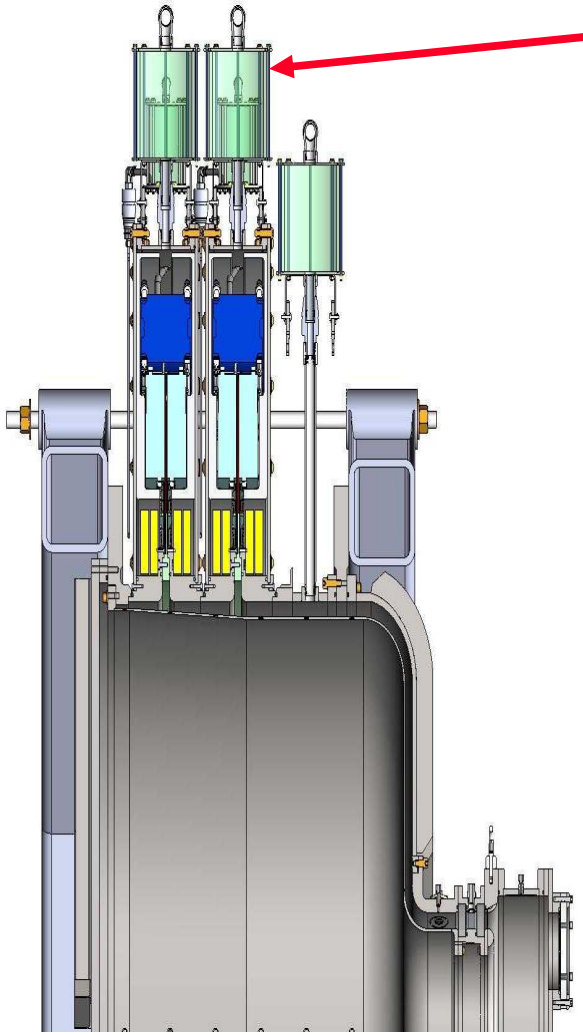
Other LTD cavity modifications Continue

10. Replace the two piece polycarbonate/ polyethylene middle A-K gap insulator with a monolithic polyurethane insulator.

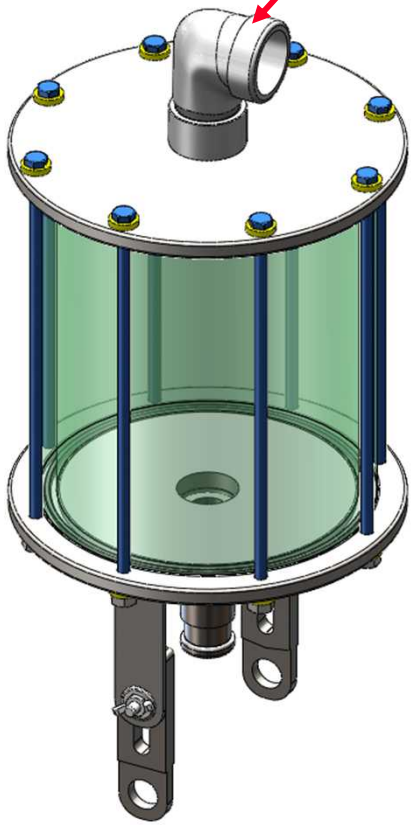




Other LTD cavity modifications Continue



11.New oil and water sight glasses



Summary of the 1-MA, Fast (100-ns), LTD experimental test results and future plans.

- 1-MA, 100-kV LTD stages individually tested met 0.1 TW output design specs.
- First tests of a five stage vacuum insulated voltage adder with resistive and diode loads demonstrated successful energy and power addition and transmission to the load.[A. A. Kim, M. G. Mazarakis, *et. al.*, Phys. Rev.ST Accelerators and Beams 12, 050402 (2009)] and [M. G. Mazarakis, A, A. Kim *et al., IEEE Trans. Plasma Sci., vol. 38, No. 4, 2010*]
- We are implementing substantial cavity modifications.
- A water insulated 2-cavity (MYKONOS II) voltage adder was commissioned and successfully operated up to 95 kV charging.
- We have fired in rep-rate mode 3,600 shots, conditioning the switches between 50 and 95kV and pulse shaping.
- Work is in progress to reach the 100-kV design charge voltage.
- Work is in progress to modify the remaining 8 cavities for the MYKONOS X 1-MA, 1-MV, 1-TW voltage adder.

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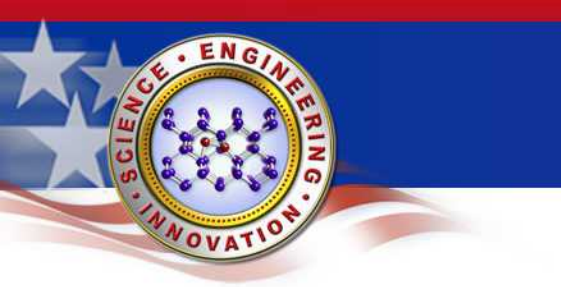

Back up slides