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A 1-MA LTD Cavities Building Blocks for Next Generation ICF/IFE

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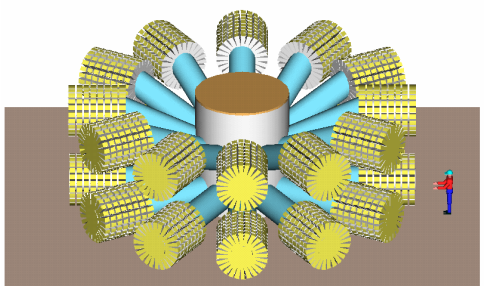
Recent Advances in High Current High Voltage Induction Voltage Adders

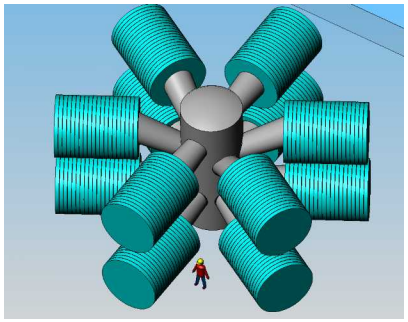
- Sandia and the High Current Electronics Institute at Tomsk Russia are the leaders toward the development of a new type of very compact high current, high voltage Voltage Adders of short 70-100-ns pulses based on the LTD (Linear Transformer Driver) technology.
- The salient feature of the the new technology is switching and inductively adding the pulses at low voltage straight out of the capacitors through low inductance transfer and ferromagnetic core isolation. High voltage is obtained by inductively adding many stages in series like in our Voltage Adder- HERMES III accelerator. MultiMegamp currents can be achieved by connecting many voltage adders in parallel.

Comparison of Existing Saturn Assembly with the Proposed New LTD

Present Device	LTD Designs	
30-m diameter.	16-m diameter.	16-m diameter
6 -m height.	5-m height	7.5-m height
250,000-gallon oil tank.	None	
250,000-gallon water tank.	None	
2 m diameter insulating stack.	None	

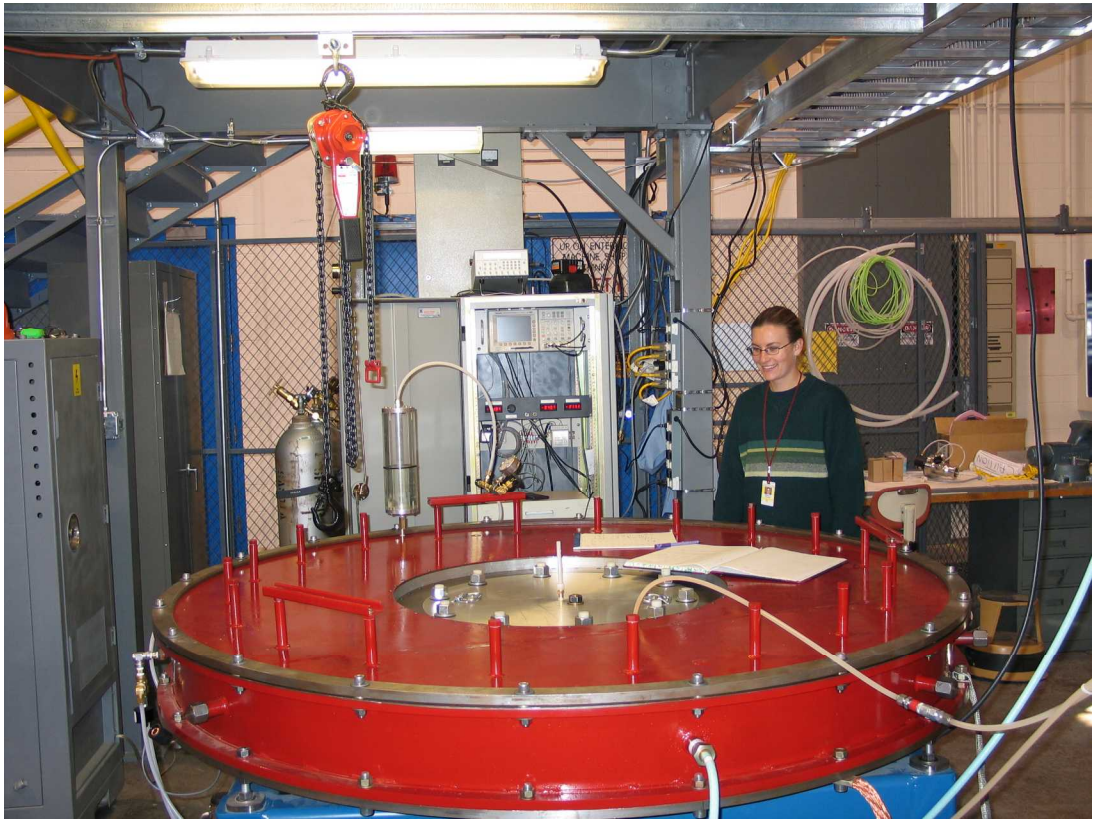


Design with 500-kA, 50-kV cavities



Design with 1-MA. 100kV cavities

500-kA, 100-kV LTD Cavity in operation



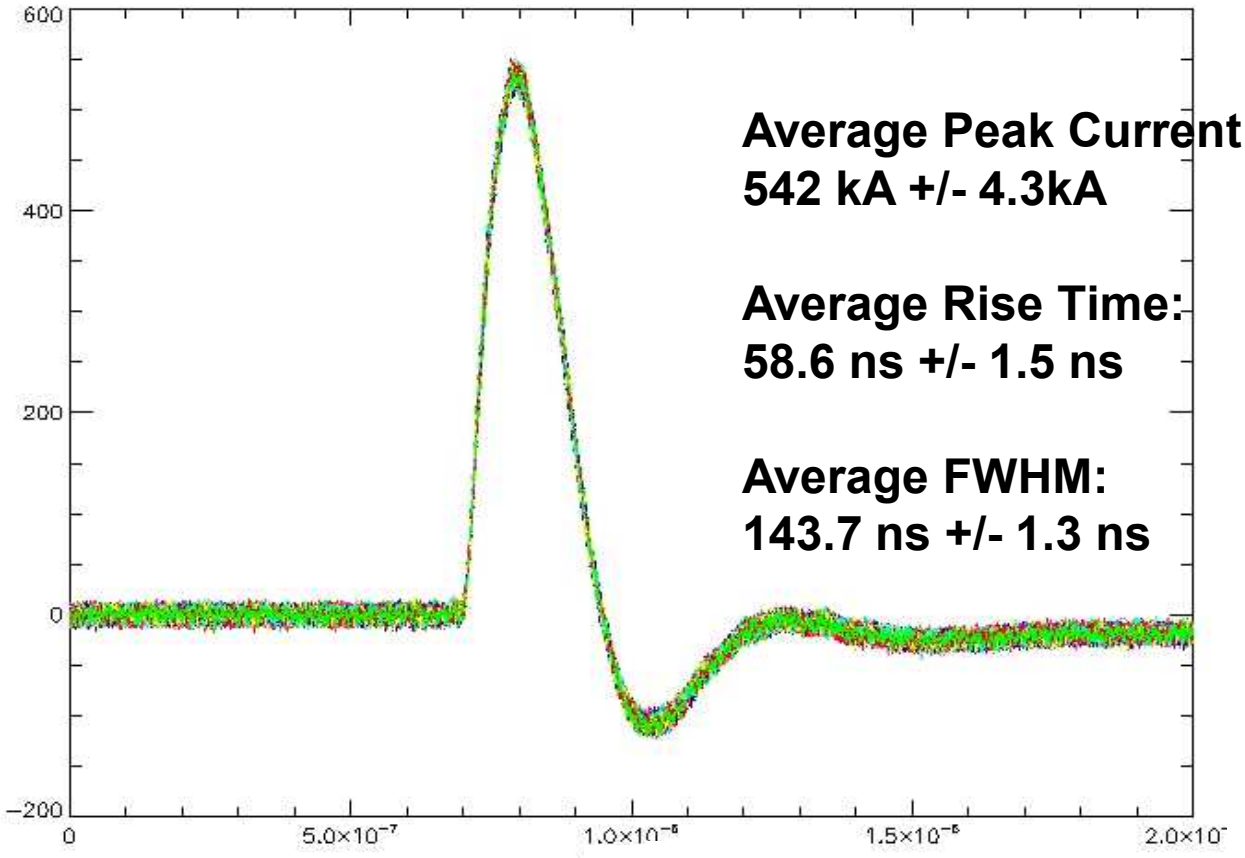
500-kA, 100-kV LTD Cavity

40 Maxwell type 31165 caps,

20 switches,

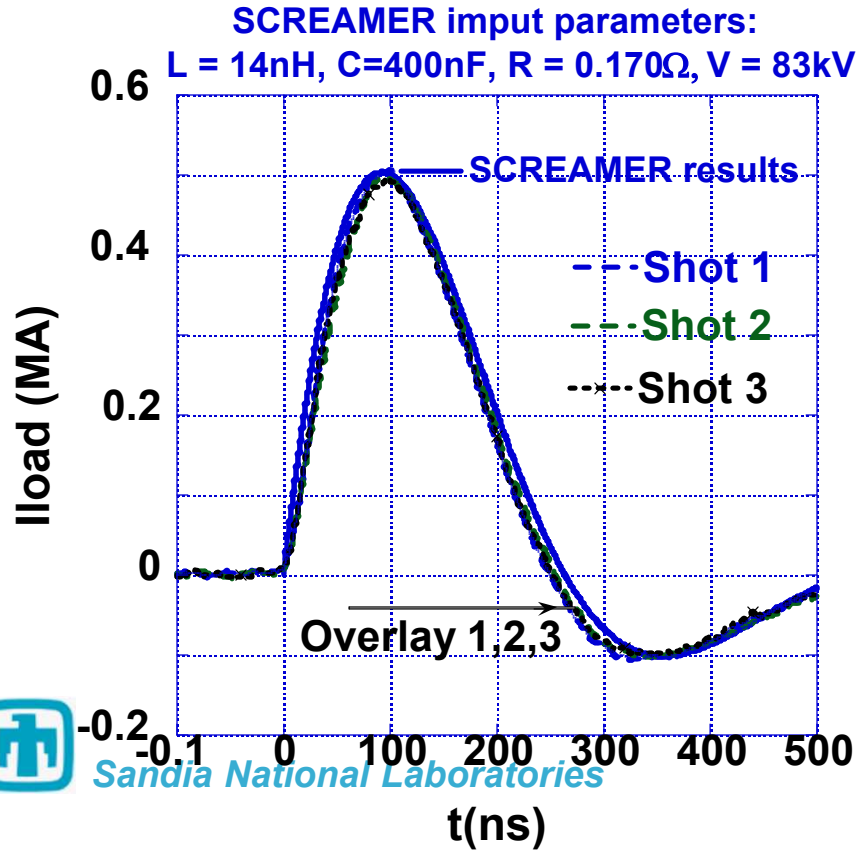
±100 kV charge,

Overlay of 100 Shot of LTD/100, 90 kV charging, in 0.03-Hz rep-rated mode

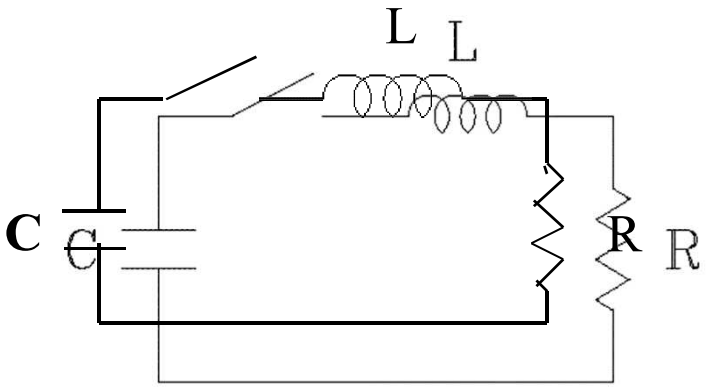


The LTD-500 Exceeded 1000 Shots in rep-rated mode at 0.034 Hz

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



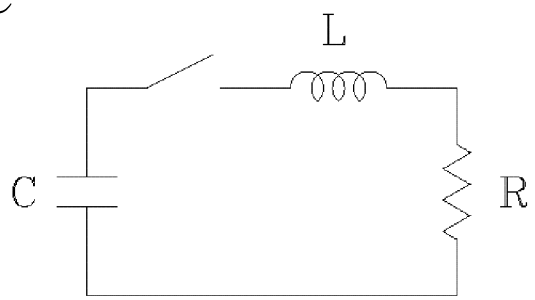
$$L \, di^2/dt^2 + R \, di/dt + i/C = 0$$



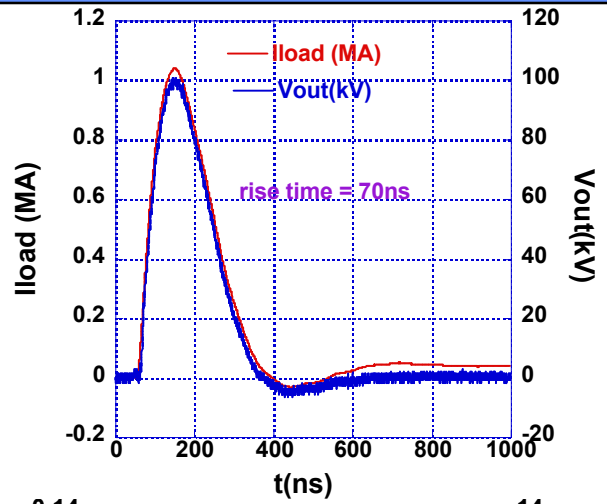
Technical approach

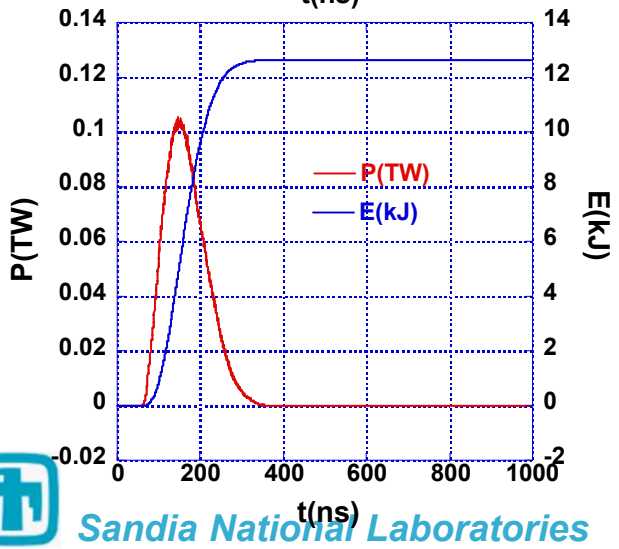
- The technical approach is based on two principles:
  - **Switching directly from the capacitors to the voltage adder.**
  - **Considering the load R as part of the RLC circuit of the pulser.**
- We use two main options in “matching” the load R to the LC of the voltage adder:
  - 1.) and 2.)

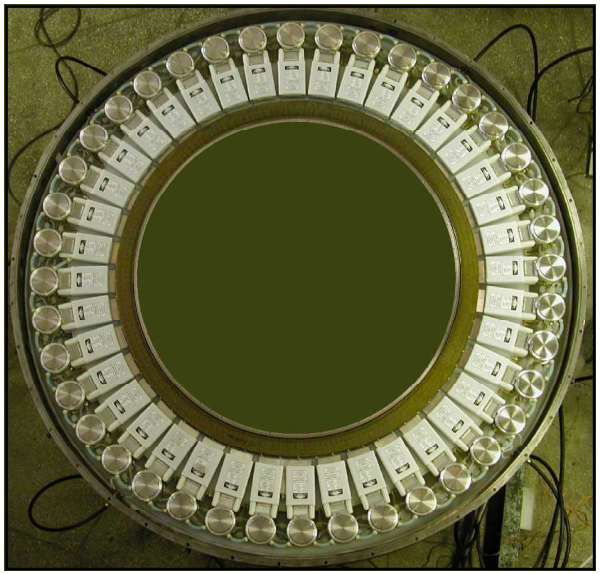
$$R = \sqrt{\frac{L}{C}} \qquad R = 2\sqrt{\frac{L}{C}}$$



1-MA LTD Cavity Performs as Expected







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

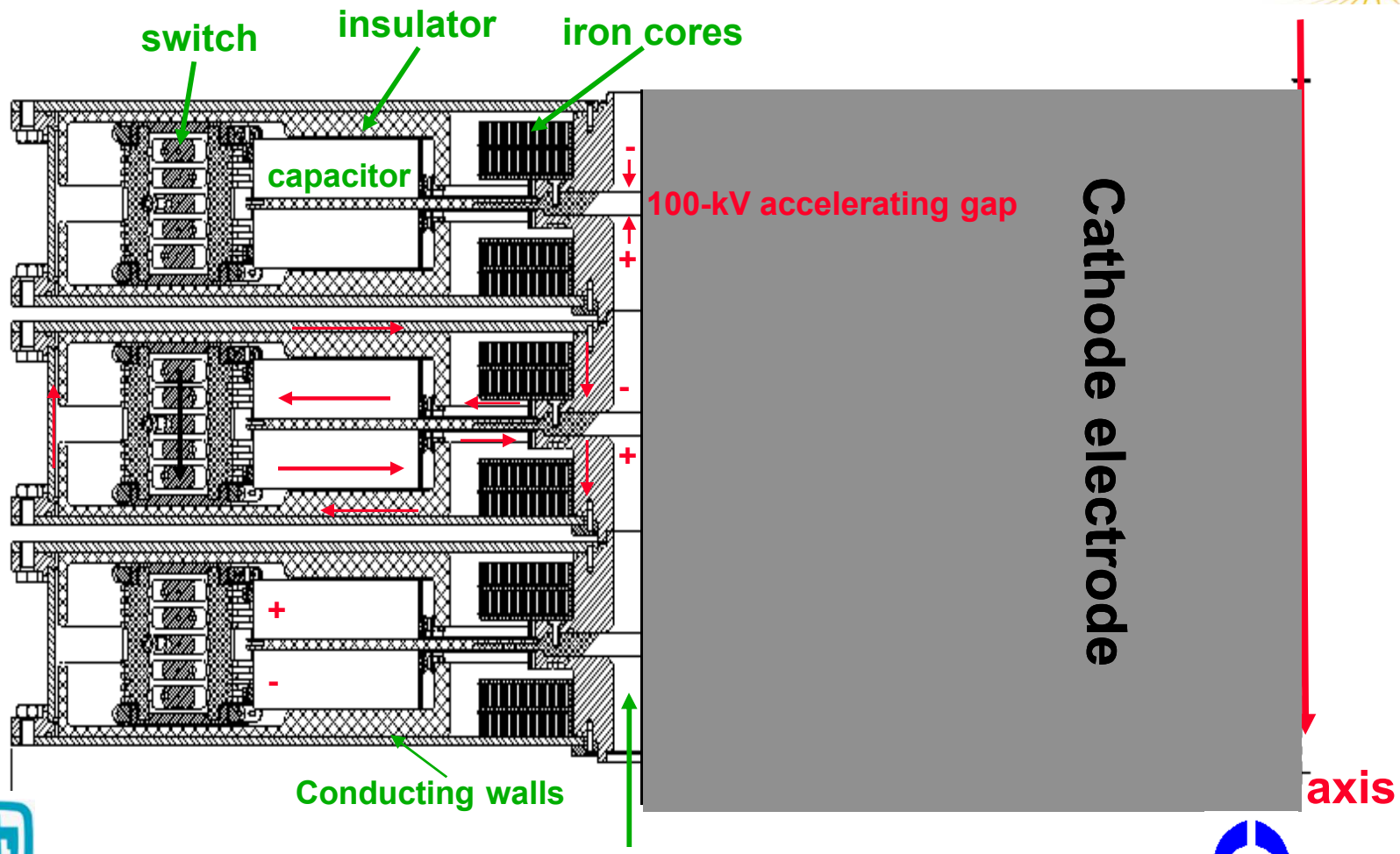
80 General Atomic Model

single ended caps,

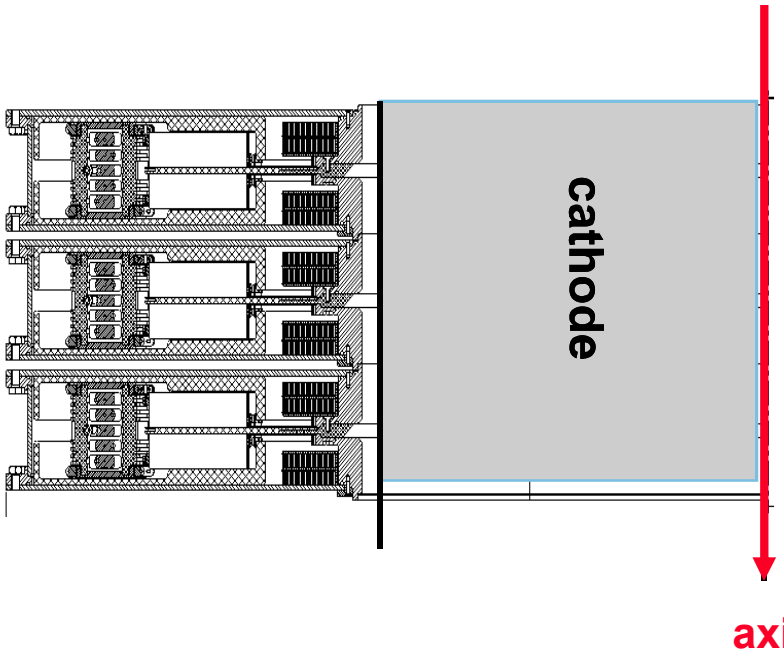
40 switches, ±100 kV

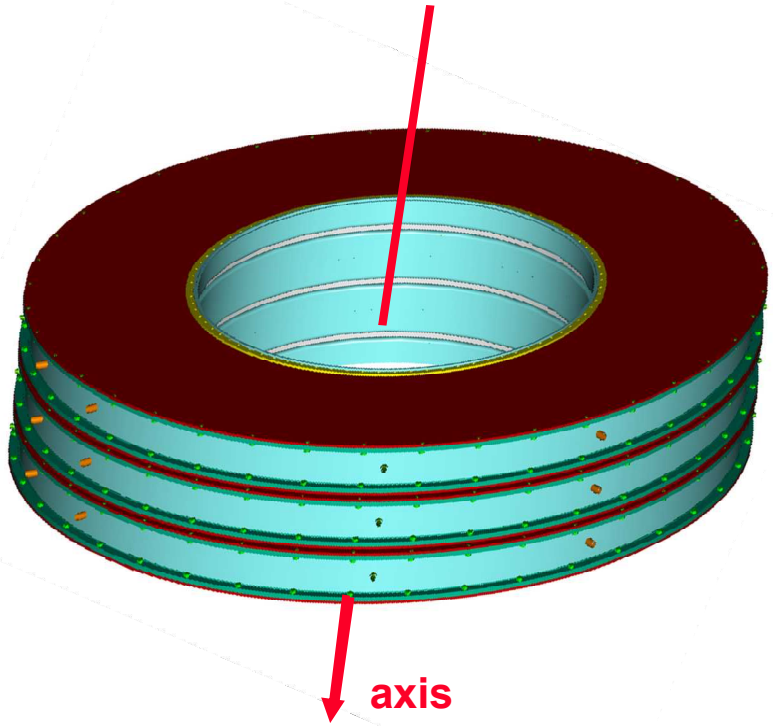
0.1 Ohm load **0.1TW**

Three 1-MA LTD cavities connected in series to form the anode cylinder of the voltage adder

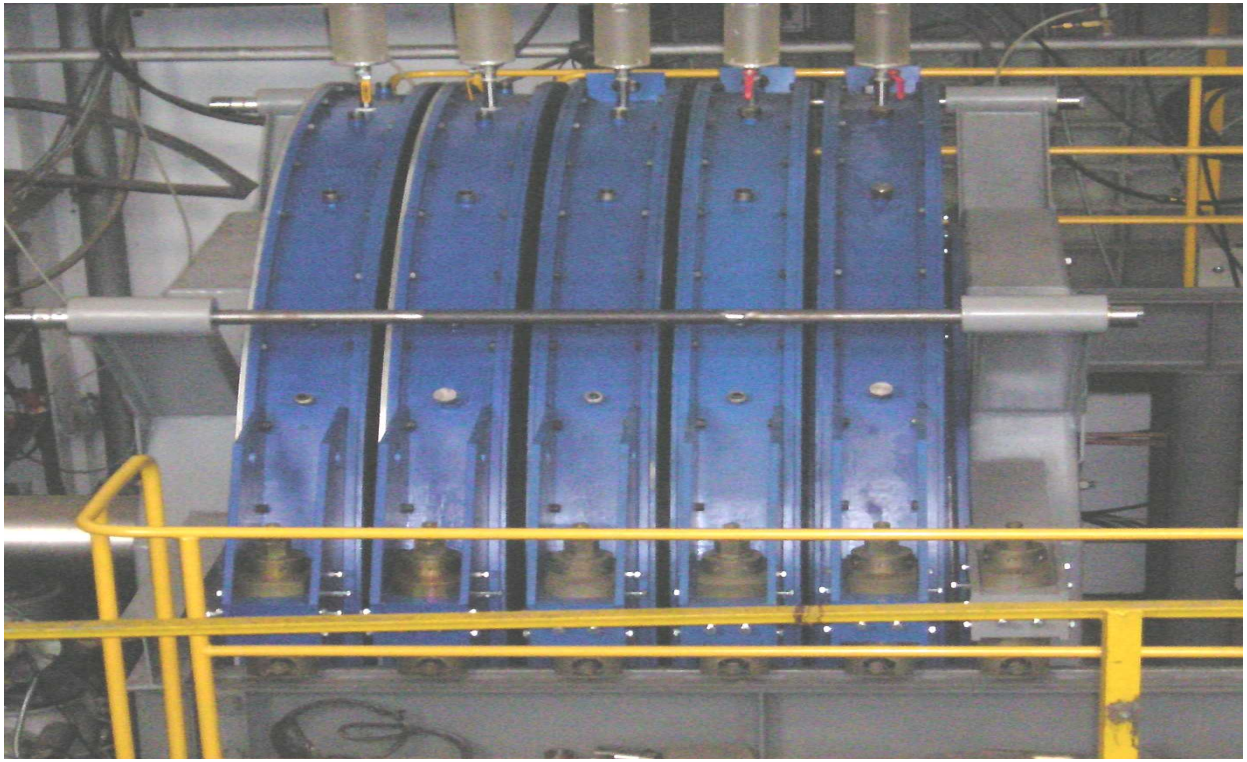


1-MA stackable LTD cavities building blocks for Z-pinch and IFE drivers

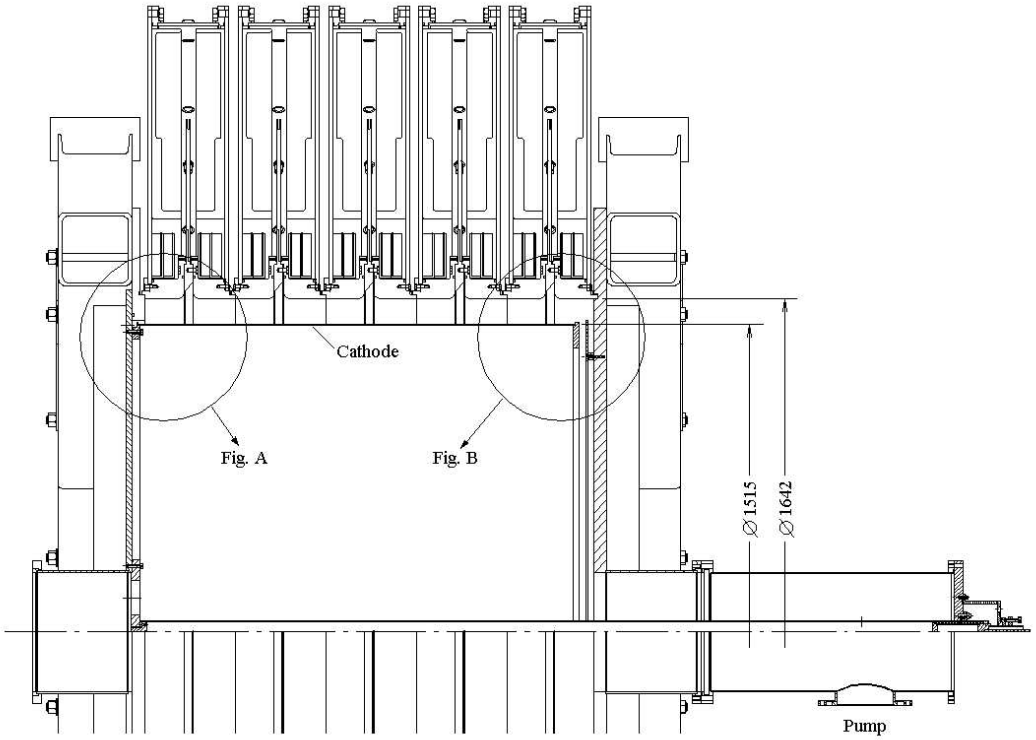




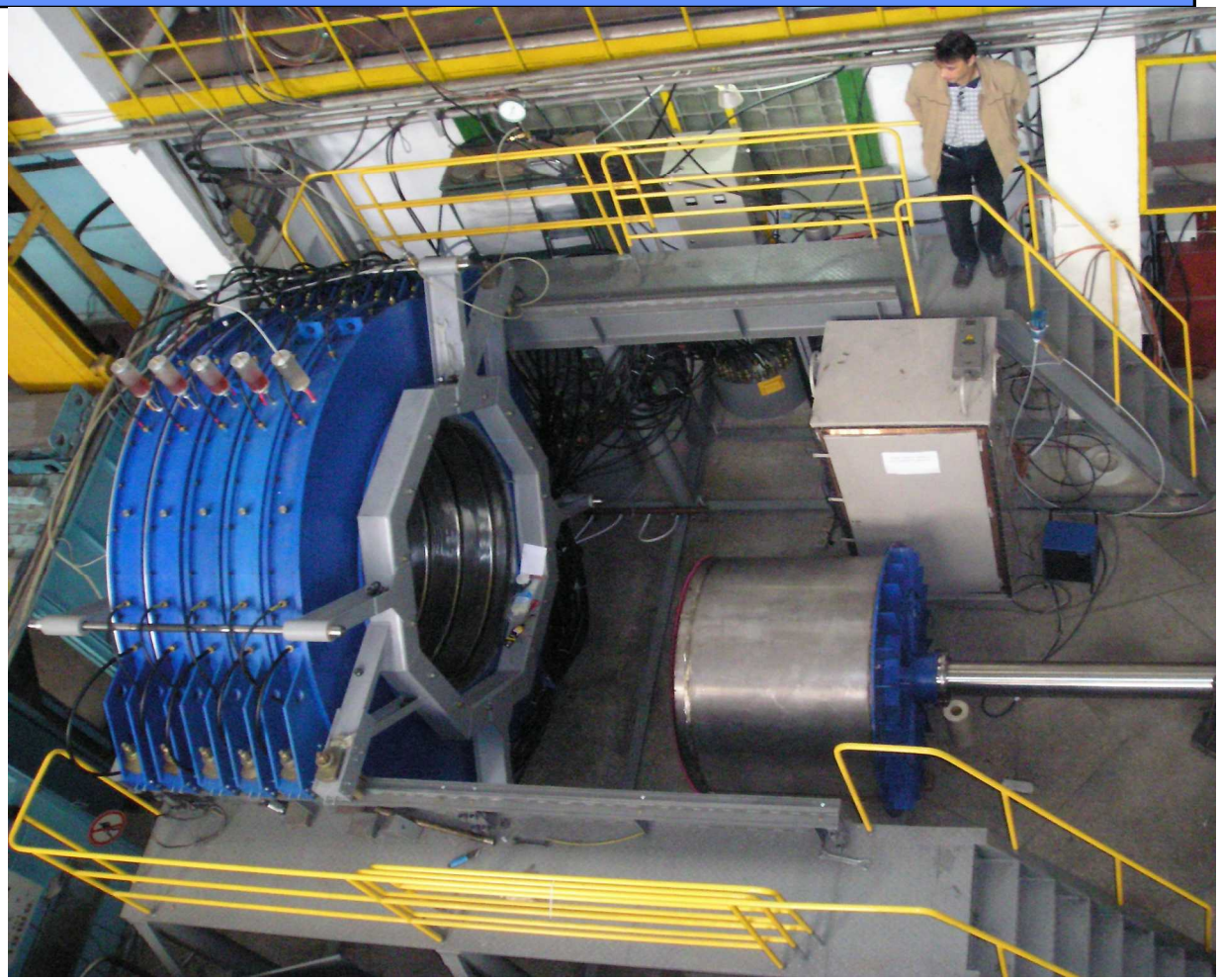
Five 1-MA Cavity Voltage Adder



Five 1- MA LTD Cavity Assembly

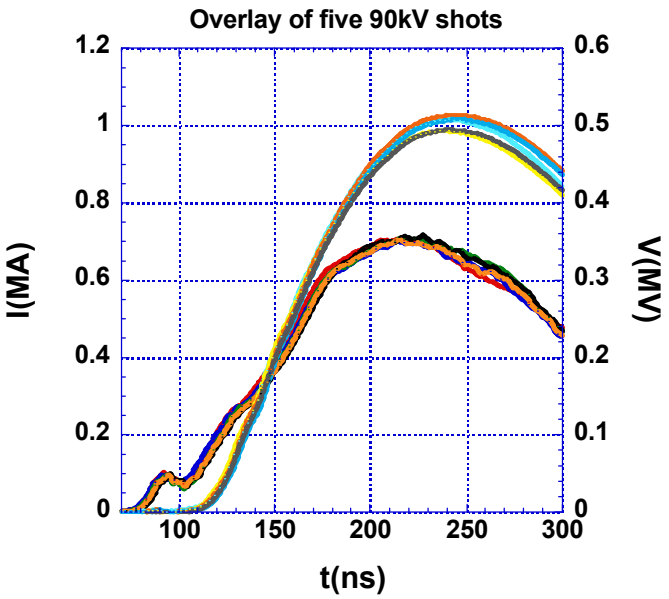


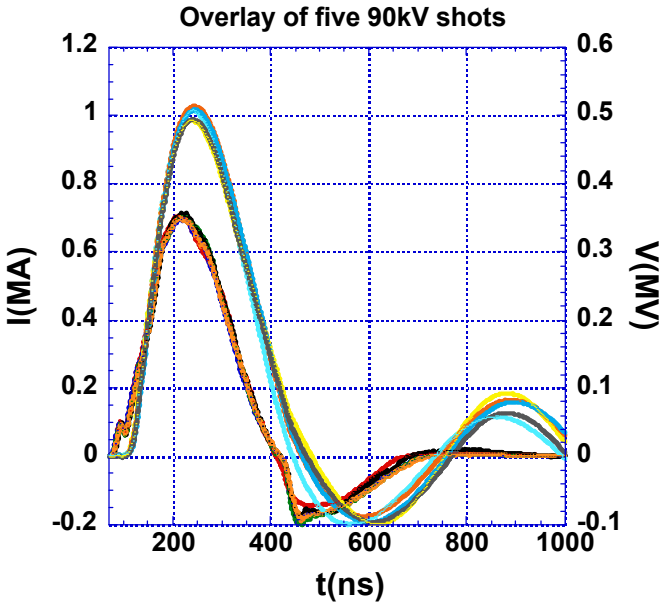
Voltage Adder Top View with Cathode Removed



Front View

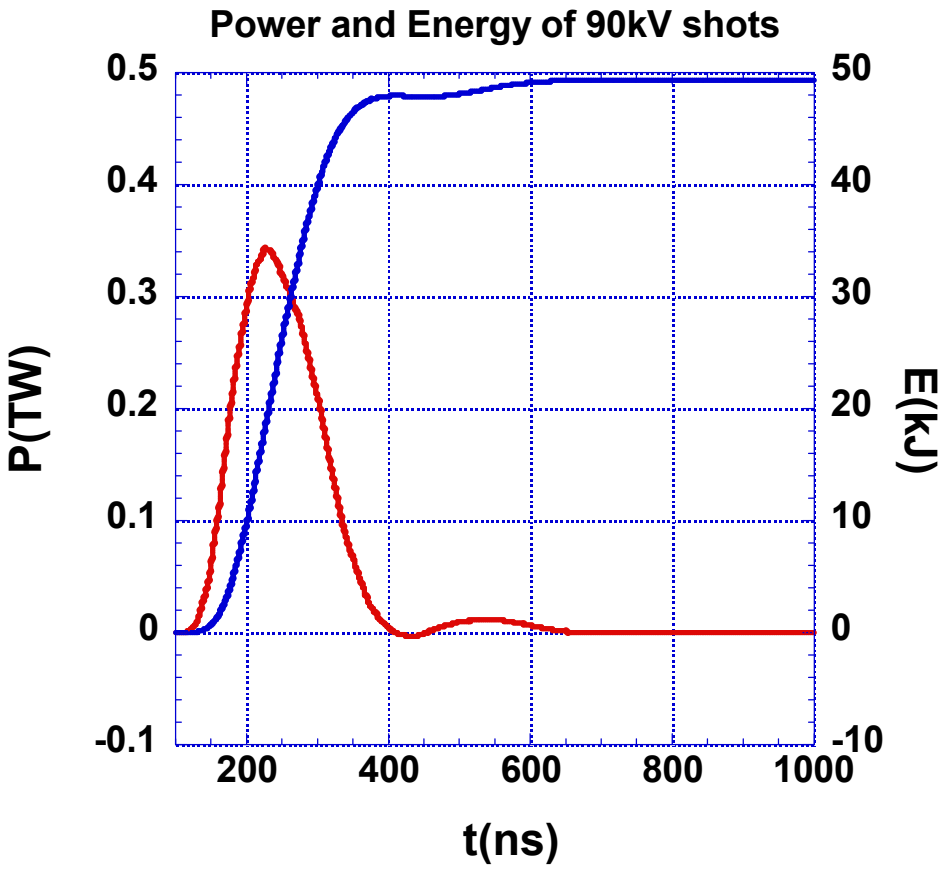
Five 1-MA LTD Cavity Data,
(Voltage and Current 90-kV Charging)



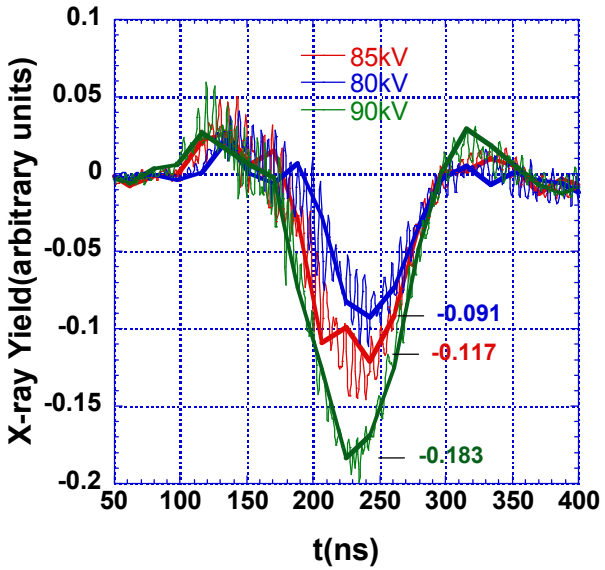


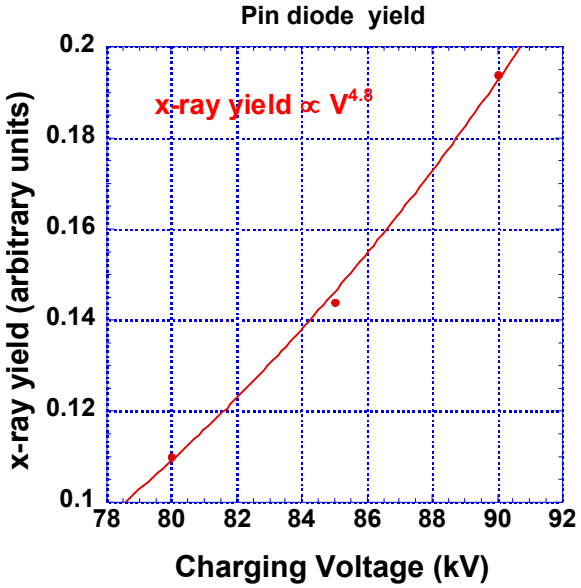
360kV pspice predicted value for 0.14 Ohm vacuum diode load,

Five 1-MA LTD Cavity Data
(Power and Energy 90-kV Charging)

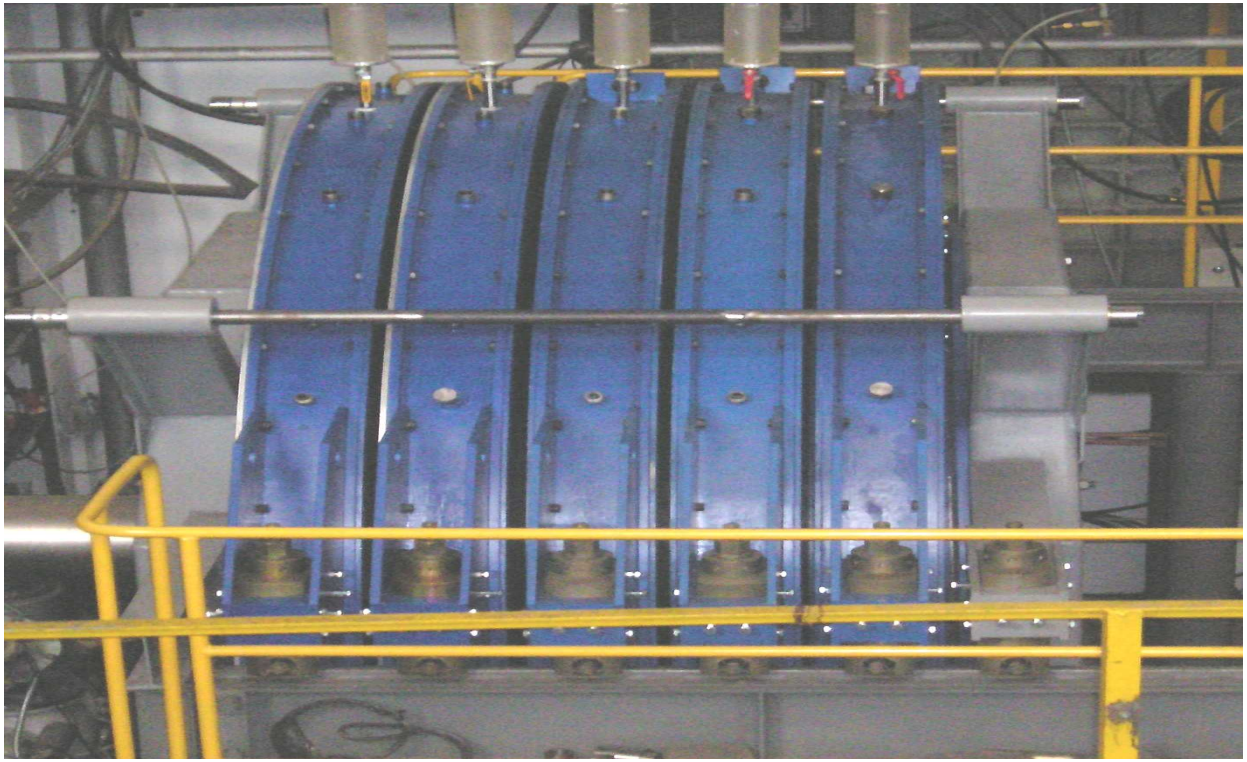


Five 1-MA LTD Cavity Data,
(X-ray Yield for 80, 85,and 90-kV Charging)

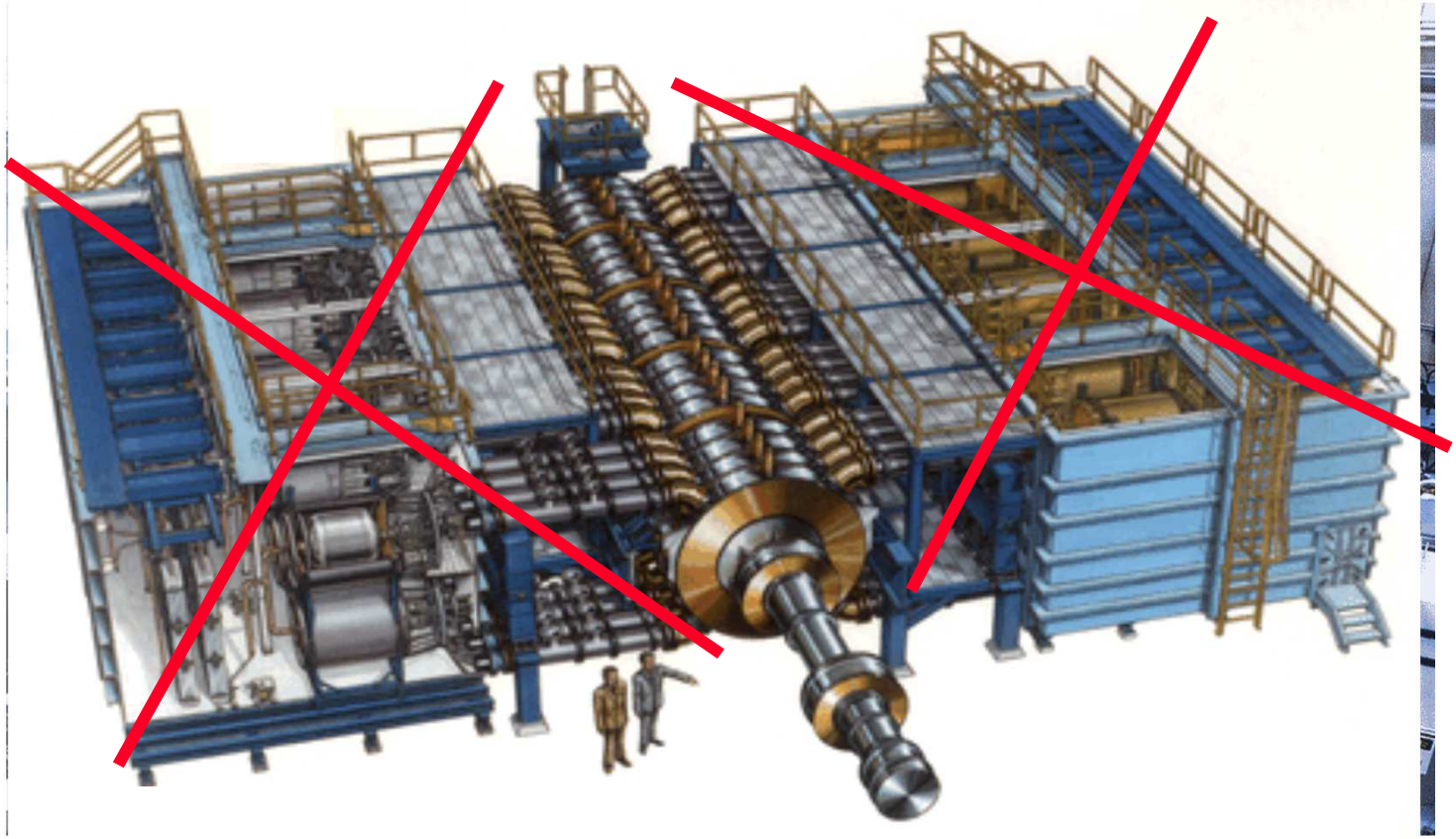




Five 1-MA Cavity Voltage Adder



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

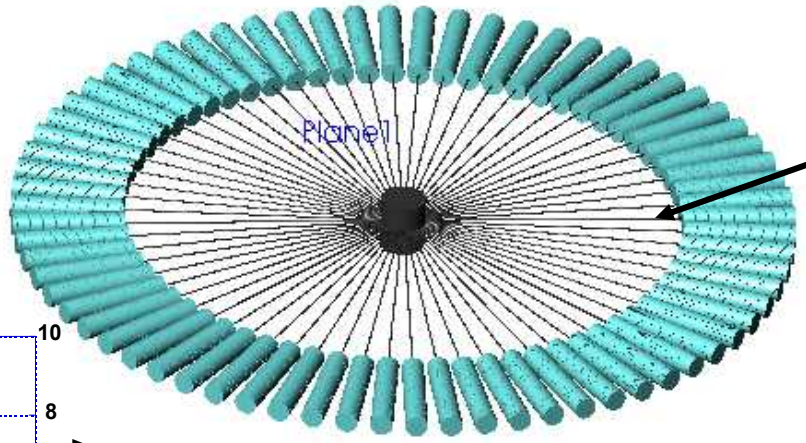


HERMES III

An IFE driver with seventy 1-MA voltage adder modules. Each module has 70 LTD cavities.

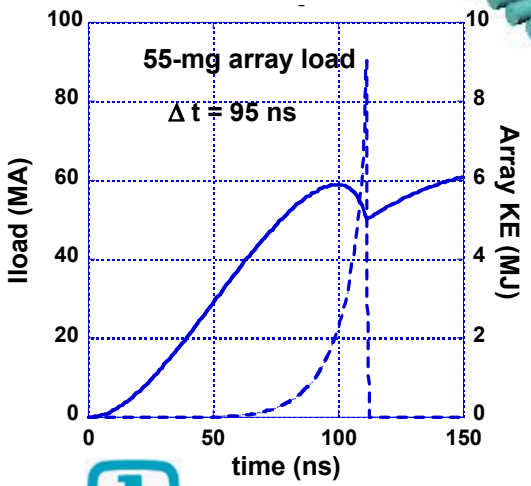
104m

Vacuum gap



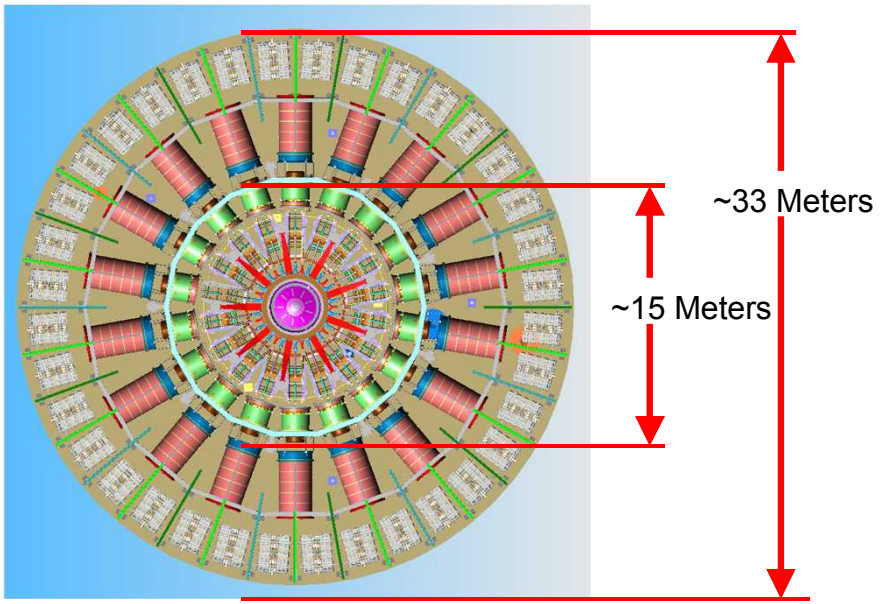
Power transmission lines,MITLs

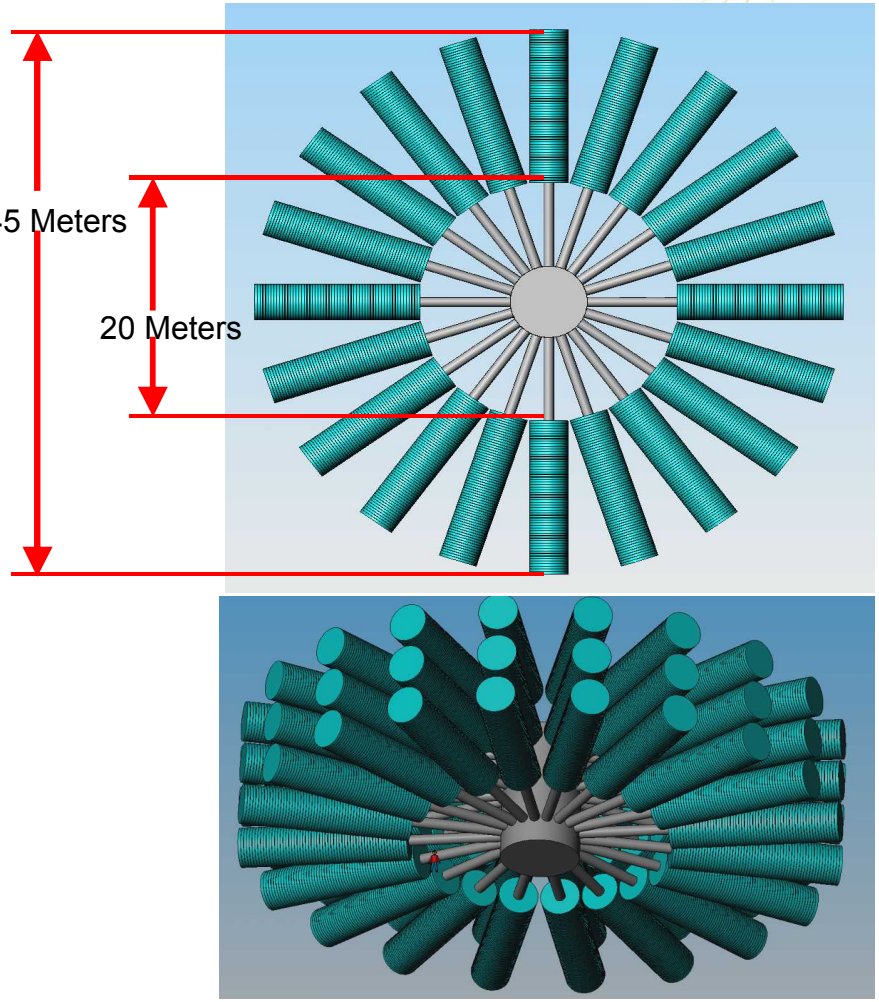
1-MA voltage adder module



A 60-MA LTD Driver designed with 1-MA cavities arranged in three levels is compared with our 26-MA ZR Driver

ZR Machine





Near future work

- System studies with more realistic components.
- Estimate losses in the long MITLs.
- Do circuit code and 3D simulations to optimize impedance matching, minimize bi-plate and RTL inductance and reduce losses in the transition region where the 70 discreet MITLs merge to a bi-plate disc.
- Do all of this in a symbiotic way with the reaction chamber and robotics requirements (IFE only).
- And…more!

Summary

- The fast LTD technology although new is mature enough to be considered for high current Z-pinch drivers and as the leading driver for an IFE system (rep-rate capability).
- Fast LTD,s are very compact devices.
- They are very close of being rep-rated to 0.1Hz.
- Their cost is relatively modest.
- Their operation is simple and reproducible.
- Very modular.
- Have the advantage of graceful degradation.
- Are self contained and do not require external pulse forming systems.

Behavior of a system with R = $\sqrt{L/C}$

- The time to peak is $t_{peak} = \frac{2\sqrt{LC}}{\sqrt{3}} \arctan\sqrt{3} \equiv \frac{2}{\sqrt{3}} \cdot \frac{\pi}{3}\sqrt{LC} \equiv \underline{1.21}\sqrt{LC}$

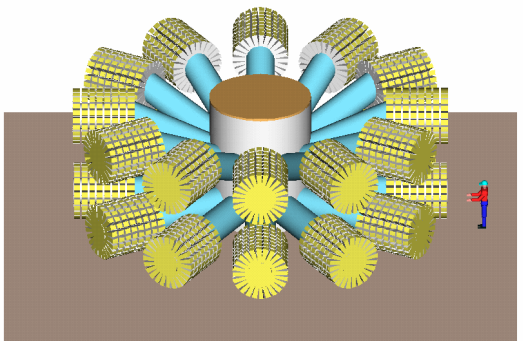
- And the peak current is $i_{peak} = \frac{2V_0}{\sqrt{3}R} e^{-\frac{\pi}{3\sqrt{3}}} \sin(\pi/3) = \underline{0.55}\frac{V_0}{R}$

- The energy $E(t_p)$ delivered to the load by the time to peak is:

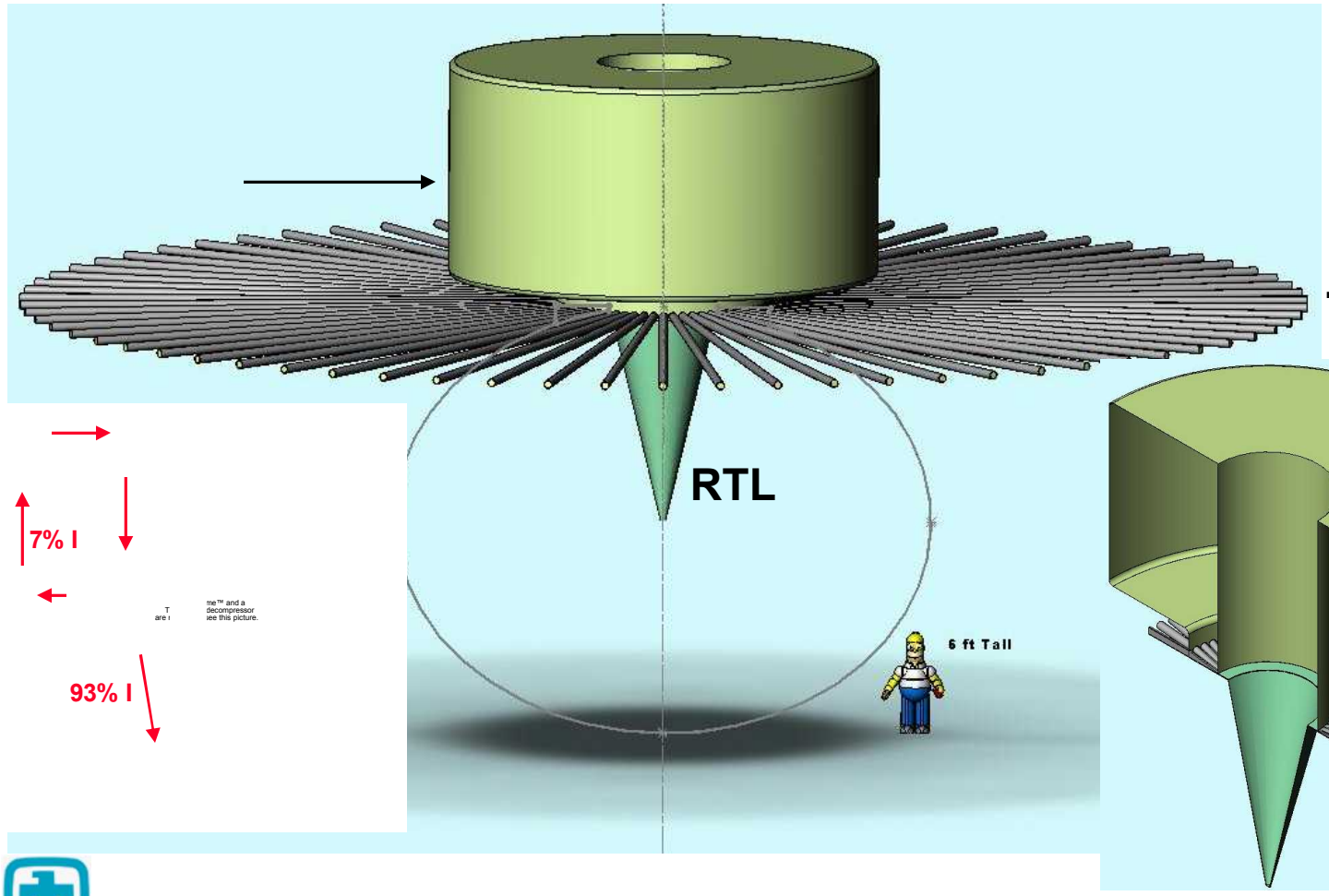
$$E(t_p) = \underline{0.403E_0}$$

Fast Linear Transformer Driver (LTD) does not need pulse compression

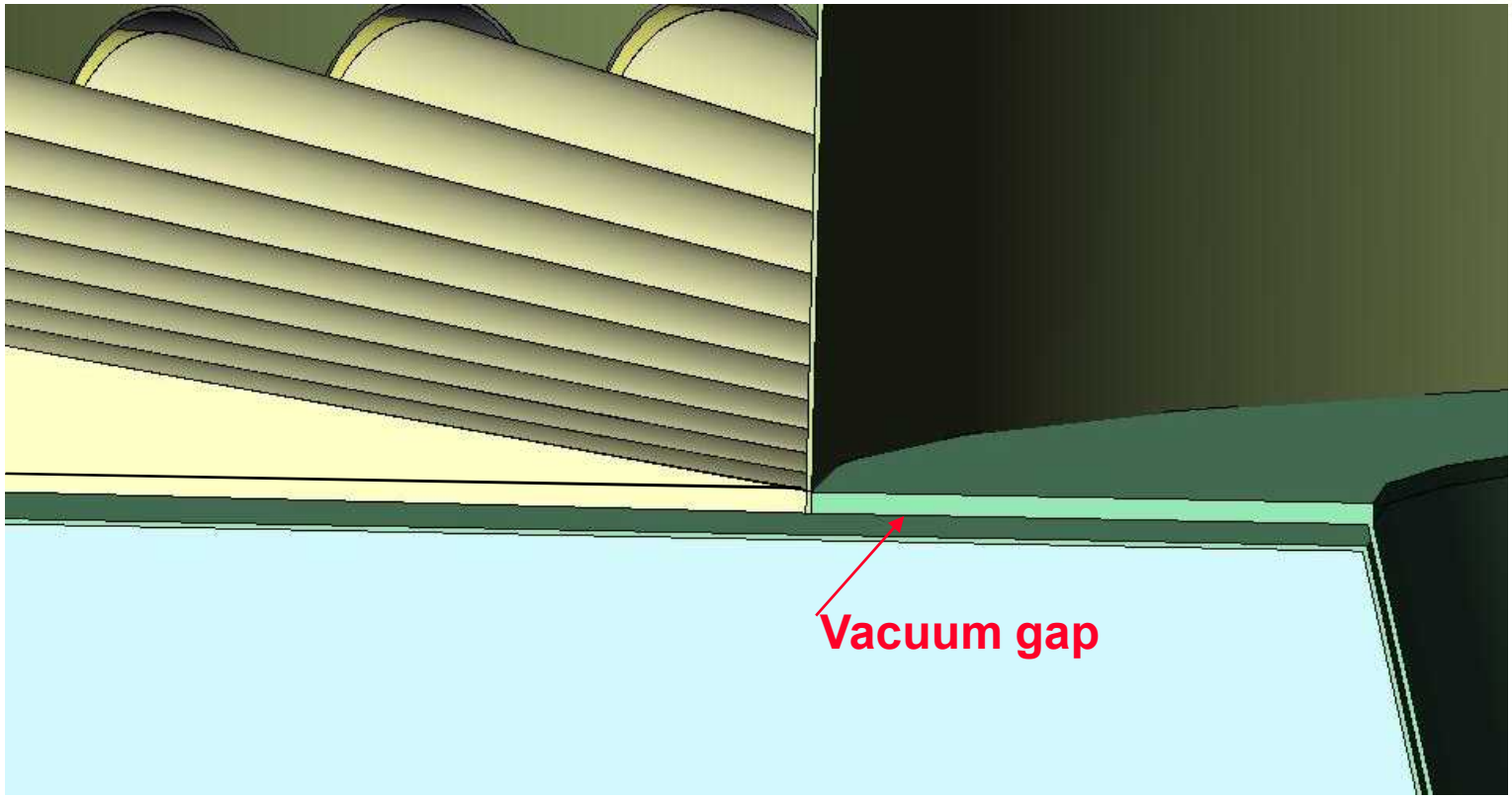
- The modern conventional pulsed power accelerators require several stages of pulse conditioning (pulse forming) to convert the multimicrosecond pulse of a Marx generator output to the 50-100-ns pulse required for Z-pinch driver.
- The LTD does not require any compression stages since the short pulse is generated right at the capacitor output discharge inside the LTD cavity.



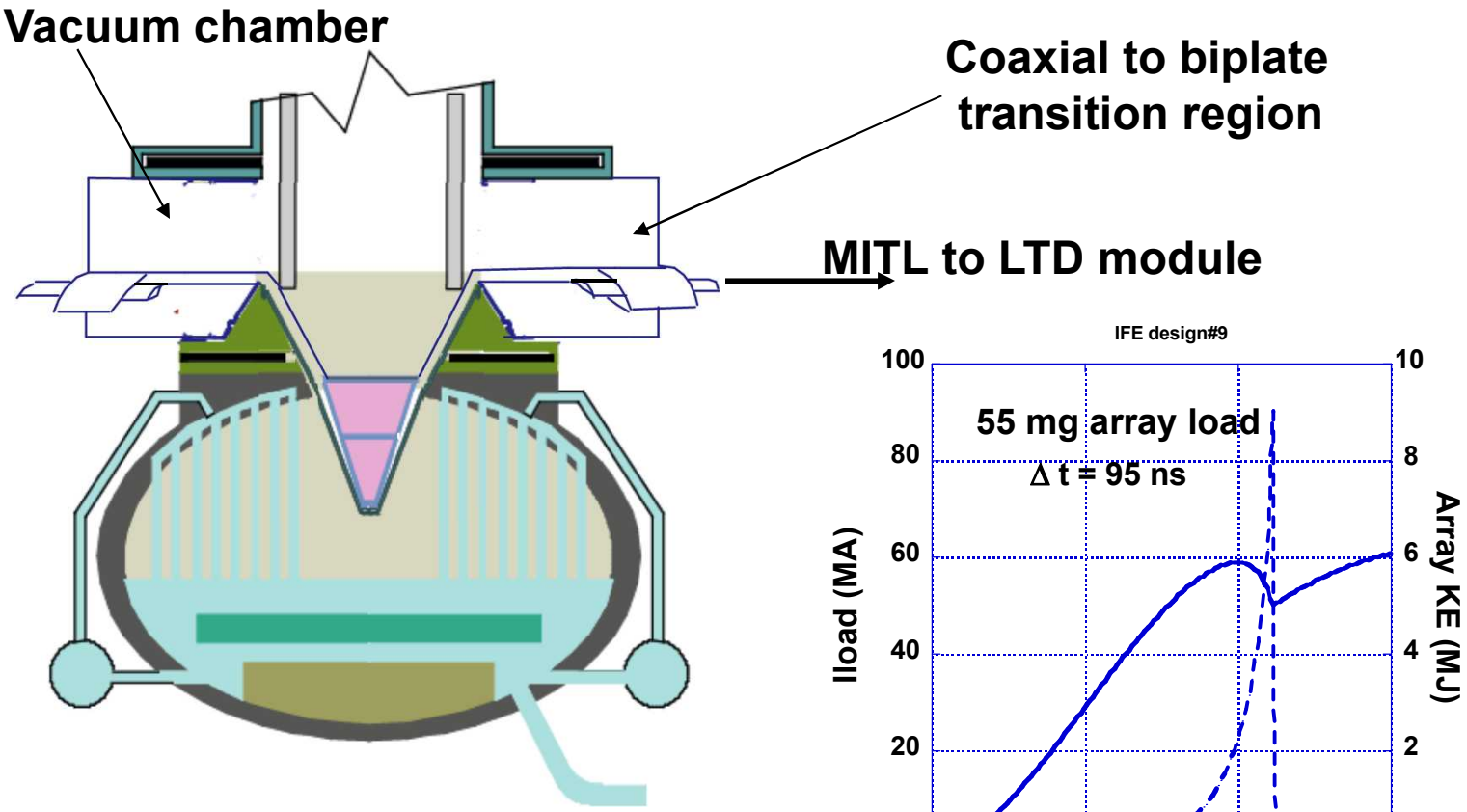
Center section of the IFE fusion reactor



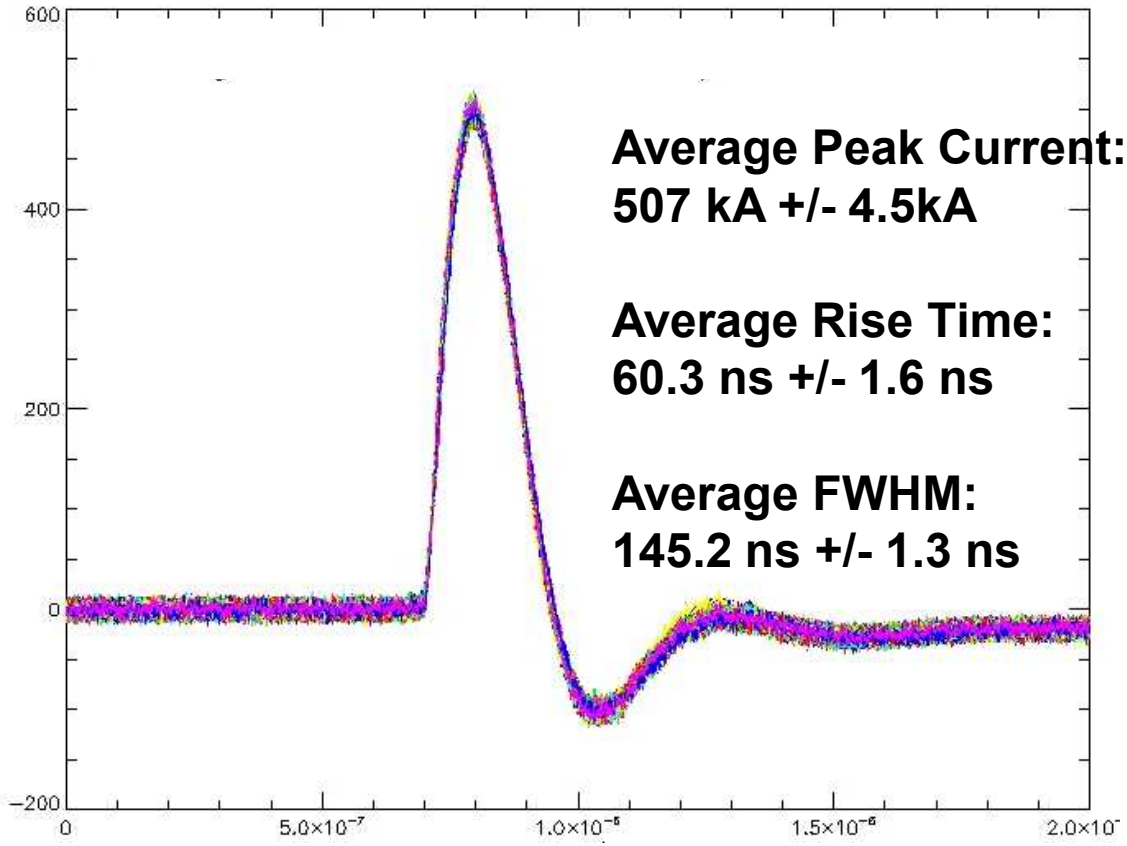
Close up of the center section



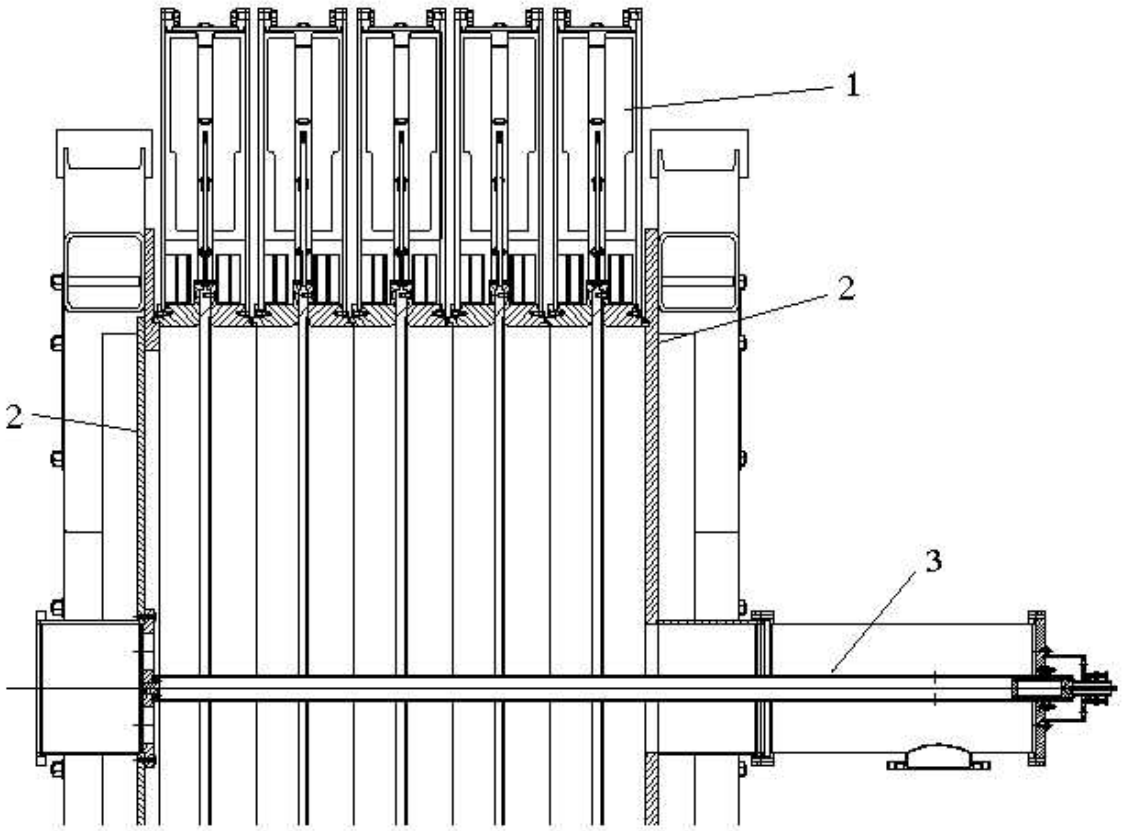
IFE Reaction Chamber Driven by 60 1-MA, 6-MV LTD Modules



Overlay of 200 Shot of LTD/100, 85 kV charging, in 0.03-Hz rep-rated mode.



Voltage Measuring Stock



"Matched" system with $R_M = 2\sqrt{L/C}$

- Here we have a simpler situation. The time to peak, peak current and voltage, and the energy transferred to the resistor by the time to peak are given by the following expressions:

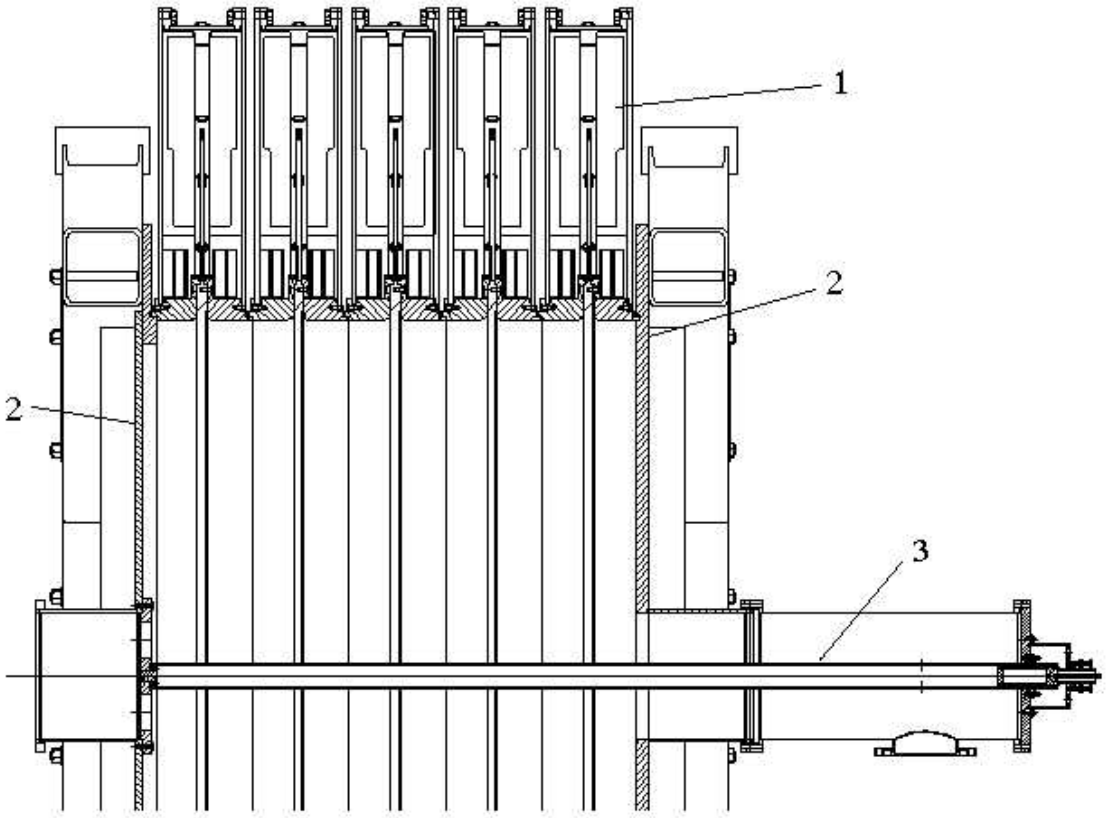
$$t_{peak} = \frac{2L}{R_M}$$

$$i(t_{peak}) = \frac{2V_0}{R_M} \cdot \frac{1}{e} = \underline{0.736}\,\frac{V_0}{R_M} = \underline{0.368}\ V_0/R$$

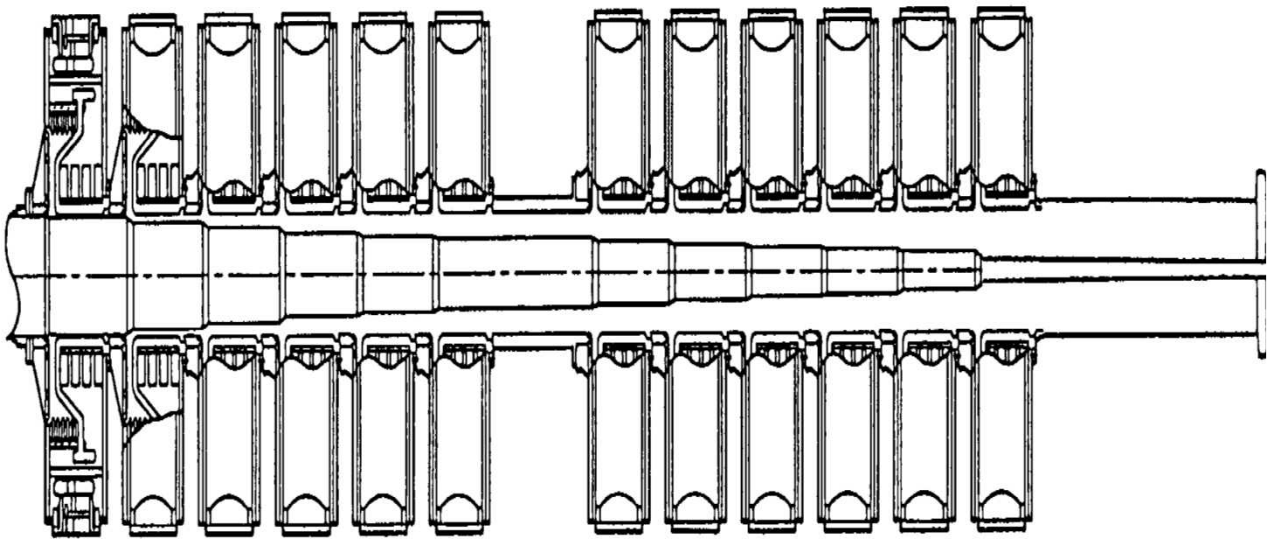
$$V(t_{peak}) = \underline{0,736}V_0$$

$$E(t_{peak}) = \underline{0.323}E_0$$

Design of the five 1-MA, 500kV LTD cavities Voltage Adder

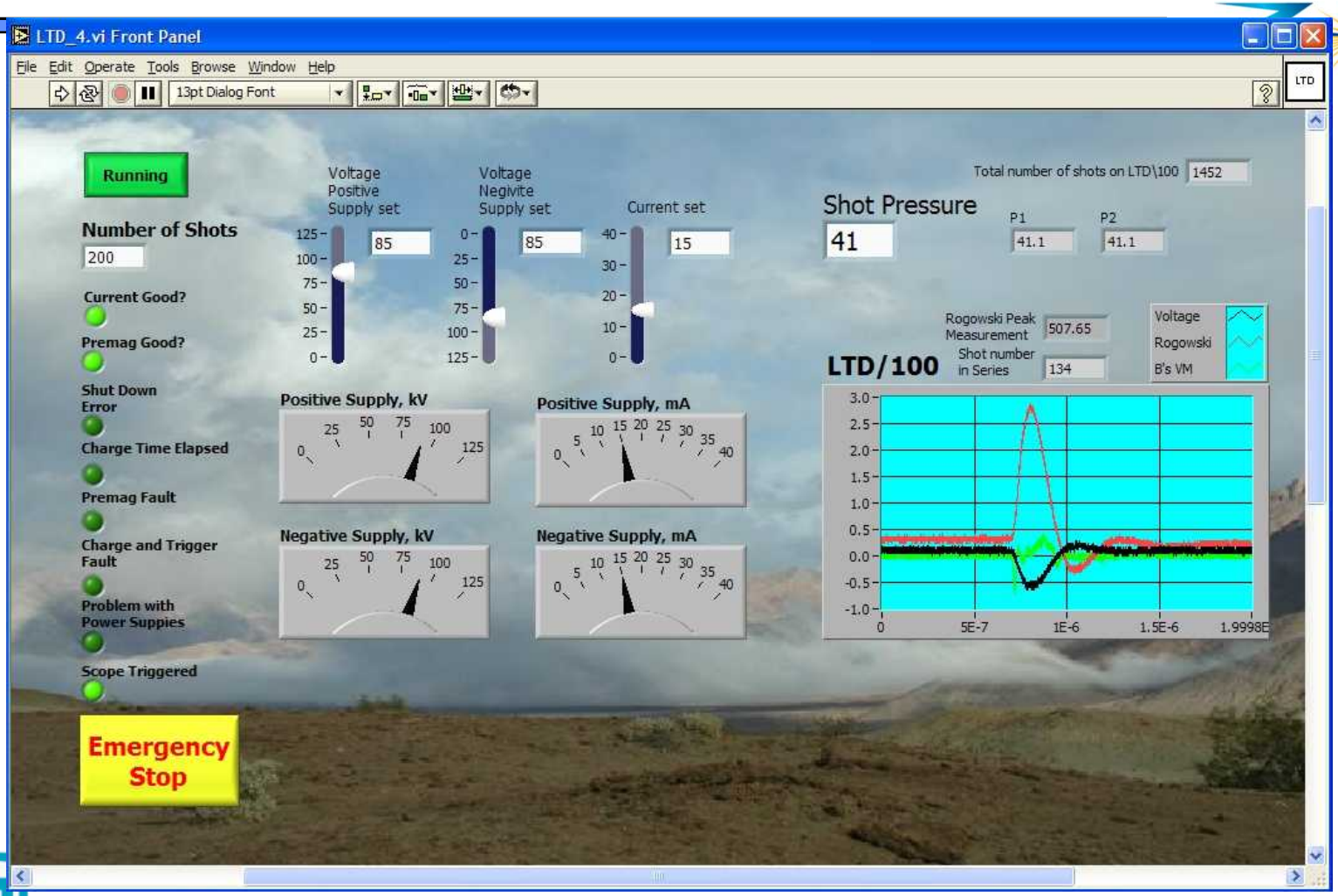


Side section of a conventional voltage adder like the one in HERMES III



Sandia High Current LTD Laboratory

Automation with LabVIEW



Schematic diagram of a basic LTD circuit or “BRICK” and switch.

The 500-kA LTD brick