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Z DRIVER POST-HOLE CONVOLUTE STUDIES UTILIZING MYKONOS-V VOLTAGE ADDER

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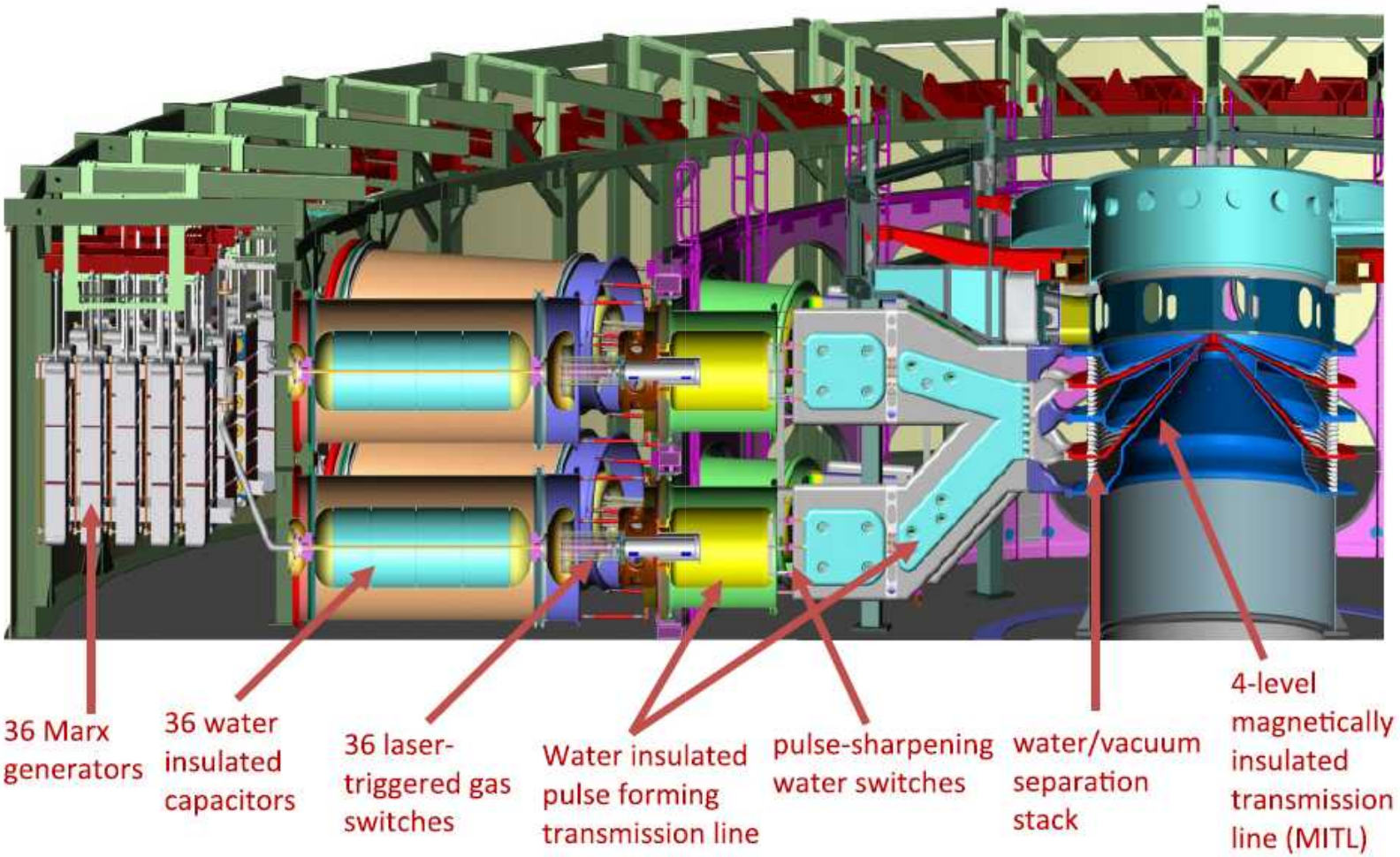
Side section of the Z pulsed power driver.

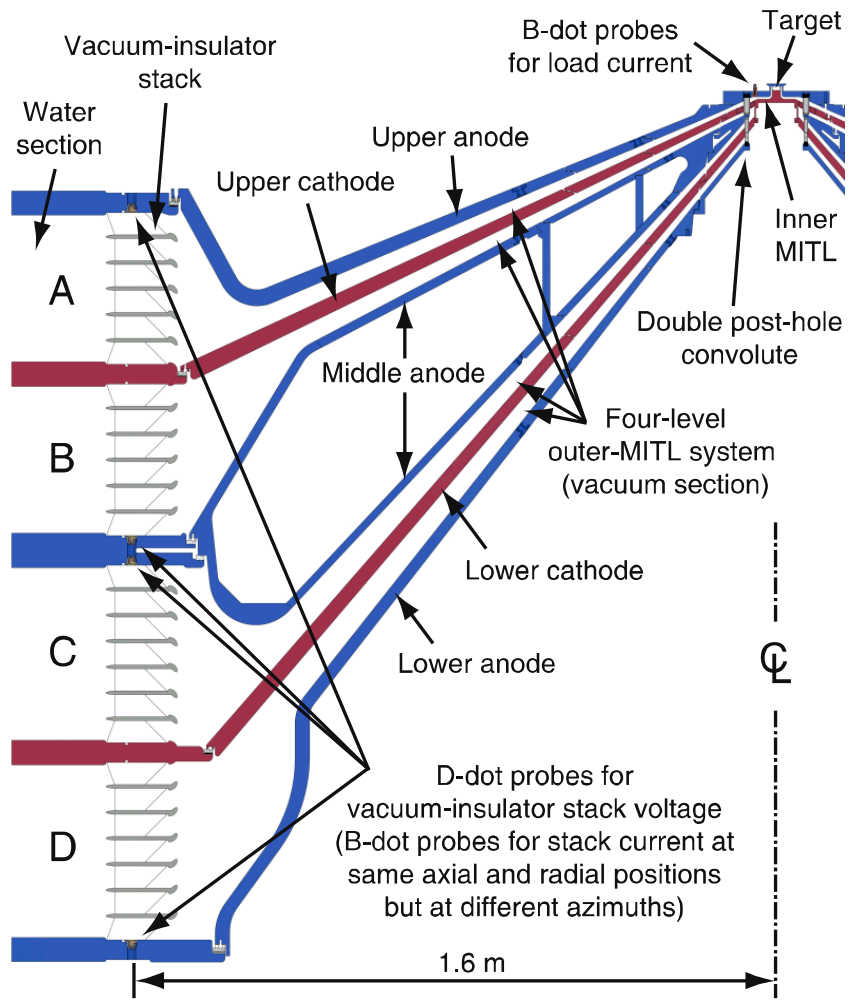


The Z- machine is the world's largest and most powerful driver.

D. H. McDaniel, M.G. Mazarakis et al, in *Dense Z Pinches AIP (2002) p.23*.
M. E. Savage, L. F. Bennett et al., 16th IEEE Pulsed Power Conference (2007) p. 979..

The post-hole convolutes add in parallel the current of several transmission lines.

- The modern high current, high voltage pulsed accelerators utilize vacuum-post-hole convolutes to add the current of a number of parallel transmission lines to the load.
- The reason is to reduce the power transfer inductance of the long (1 -2 m) power pulse transmission length.
- Specifically, the vacuum chamber of the 26-MA Z machine has a 1.45-m radius vacuum section containing four parallel conical self Magnetically Insulated Transmission Lines (MITL).
- 12 Double post-hole convolutes are utilized to add the current into a single 6 cm radius disc MITL. The convolute array is located at 7.6 cm radius from the center axis.



Z vacuum MITL,s

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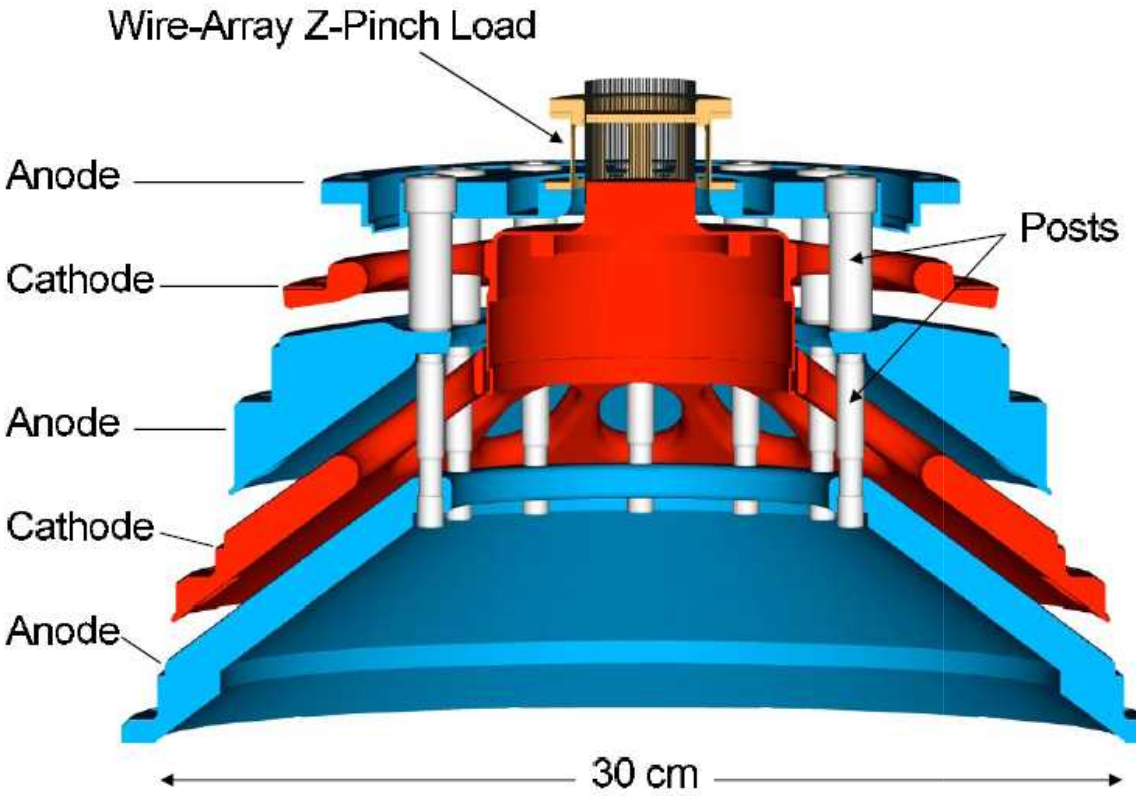
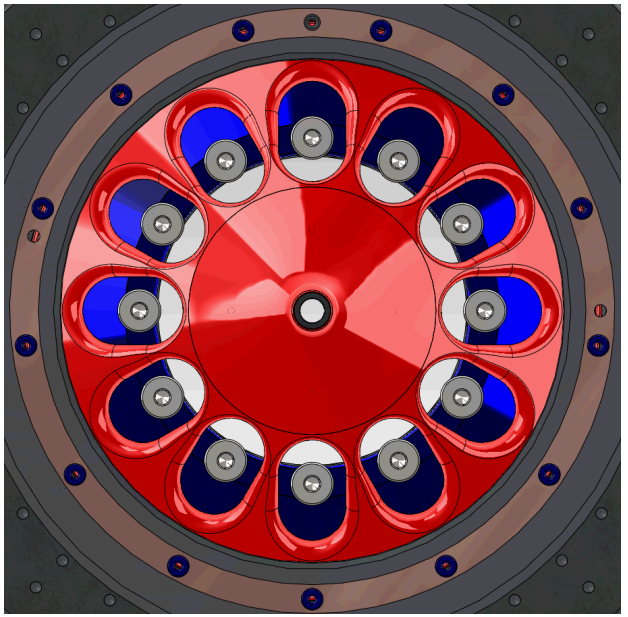
The Z vacuum double post-hole convolutes.



Side section



Top view

Z has 12 double post-hole convolutes symmetrically located around the central section.

We will use MYKONOS-V to study and hopefully eliminate the convolute current losses.

- The current addition with the post-hole convolutes is effectuated by connecting the anodes of the MITLS with a post which passes through a hole in the cathode electrode.

- Although special care has been taken to reduce the electrical stresses on the cathode hole surfaces of the Z convolutes, substantial current losses, 4-6 MA, are observed.
- It is suspected that the current losses are most probably due to plasma formation and partial current shorting at the convolutes.

- In the proposed experiments we will study the behavior and the current losses of only one Z- post-hole convolute location using the MYKONOS-V driver.

Reducing the convolute current losses is one of the most important Z challenges faced to-date.

MYKONOS – V pulse driver.

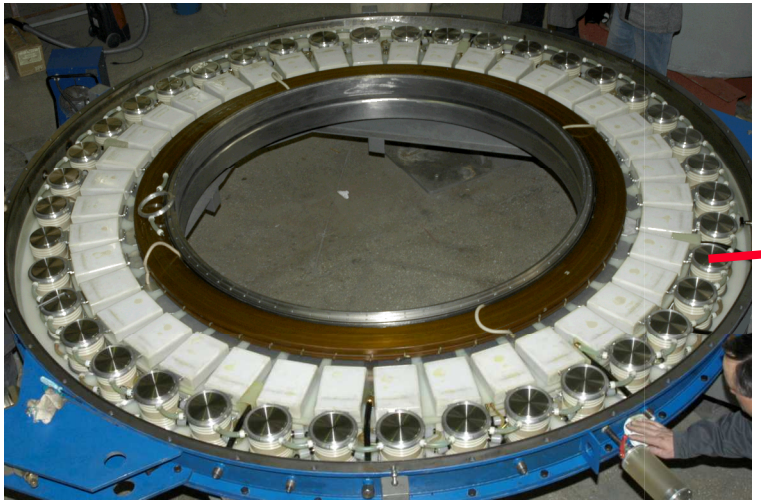
- The MYKONOS-V pulsed driver is an induction voltage adder composed of five 1-MA Linear Transformer Driver (LTD) stages connected in series.
- The voltage adder is insulated with deionized water. MYKONOS-V as well MYKONOS II are the first induction voltage adders utilizing de-ionized water for insulation.

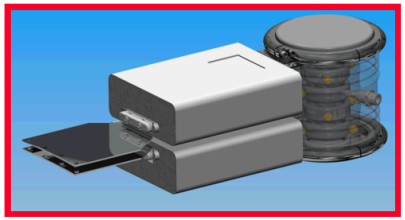
Five 1-MA LTD cavities connected in series

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

A 1-MA, 100-kV, 100-ns LTD stage.

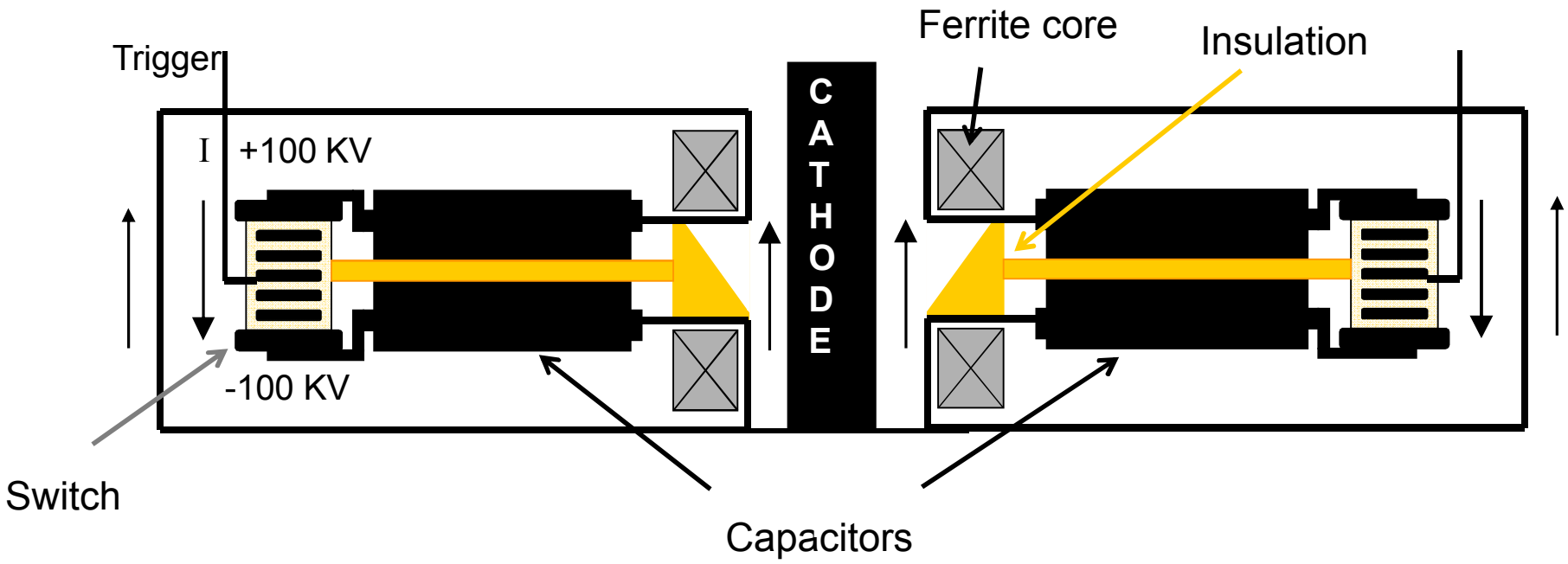
- A 1-MA LTD stage contains two circular capacitor arrays. The capacitors of the top array can be charged up to + 100kV, while the capacitors of the bottom array are charged up to – 100 kV.
- Each pair of negatively and positively charged capacitors (named brick) is connected in series with an individual 200 kV switch.
- When the switches close a voltage pulse is applied at the AK gap of the cavity located at the middle axial plane. In the case of a matched load the pulse amplitude could have a maximum of 100 kV.





A brick

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



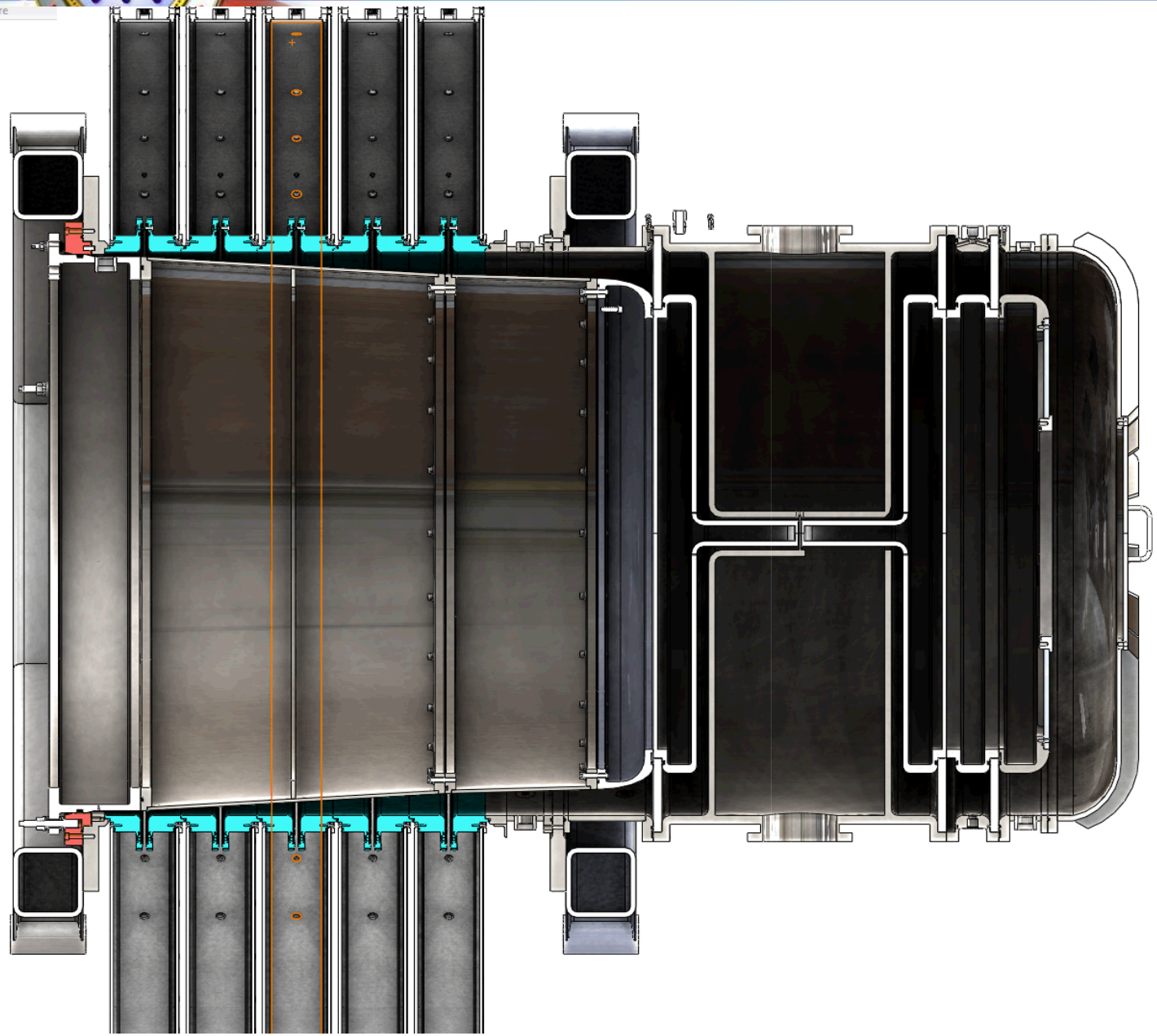
MYKONOS-V convolute experiment goals.

- Design hardware so the physics parameters existing on the Z convolutes could be duplicated on Mykonos V experimental setup (only one convolute).
- Measure current losses.
- Establish the onset of plasma formation by varying the electric field on the convolute cathode hole.
- Spectroscopic study the source and the amount of convolute plasma formation.
- Apply current losses mitigation techniques:
  - Heating Electrodes to > 100^0 C.
  - RF cleaning.
  - Vacuum effect.
- Evaluate ways of applying current loss mitigation techniques on Z convolutes.
- Perform experimental verification on Z.

We have considered two designs.

- Both designs take advantage of the existing MYKONOS hardware.
- The electrical parameters of the components of each design are estimated.
- An effort was made to minimize the total inductance and resistance of the setups attached at the end of MYKONOS - V.
- Numerous circuit code simulations were carried out to evaluate the level of reflections and voltage and current wave forms on the load downstream of the convolutes.
- A minimum number of LSP simulations will be necessary to validate the selected option before engineering design implementation.

Selected optimum design (side section).



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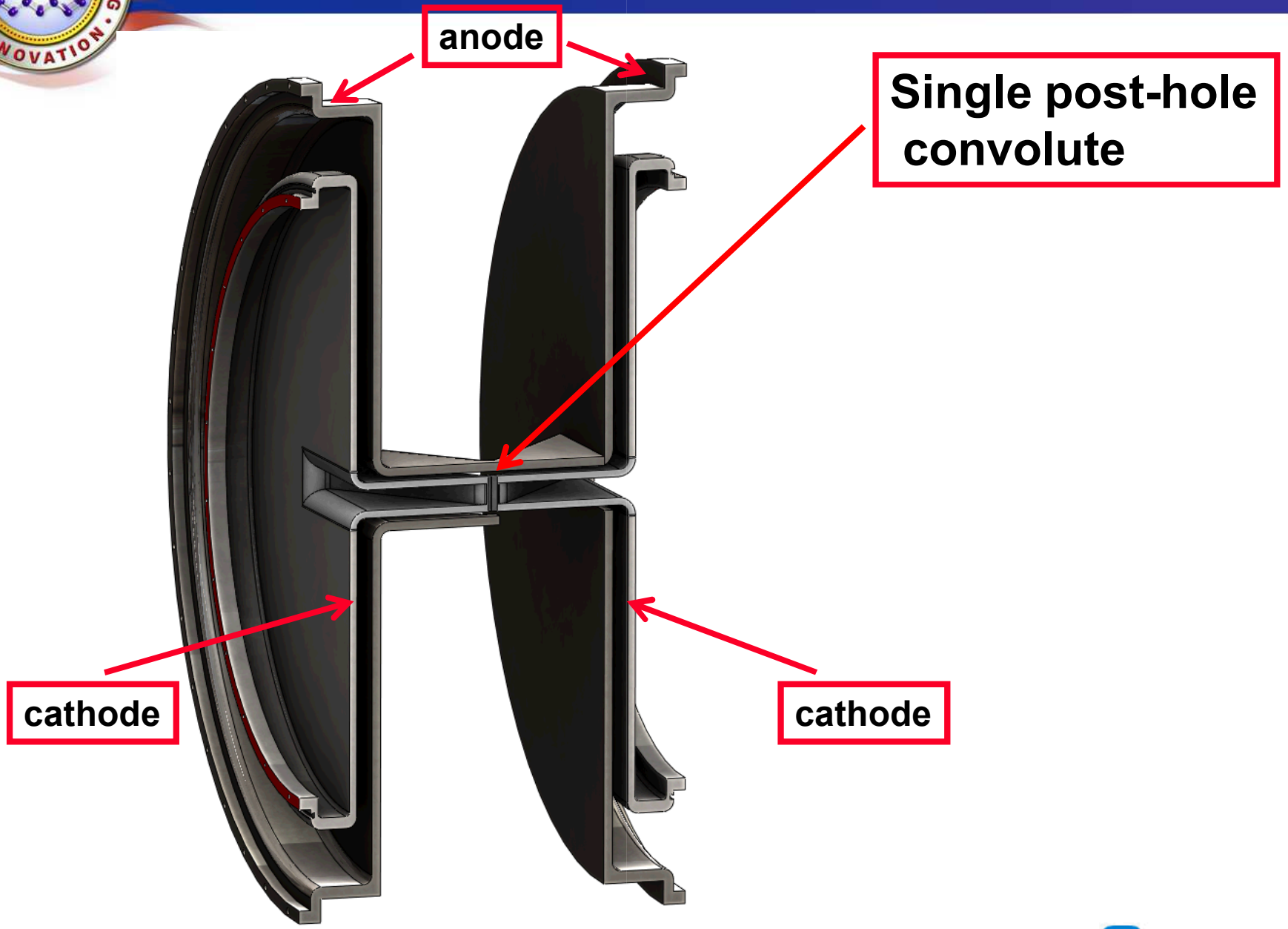
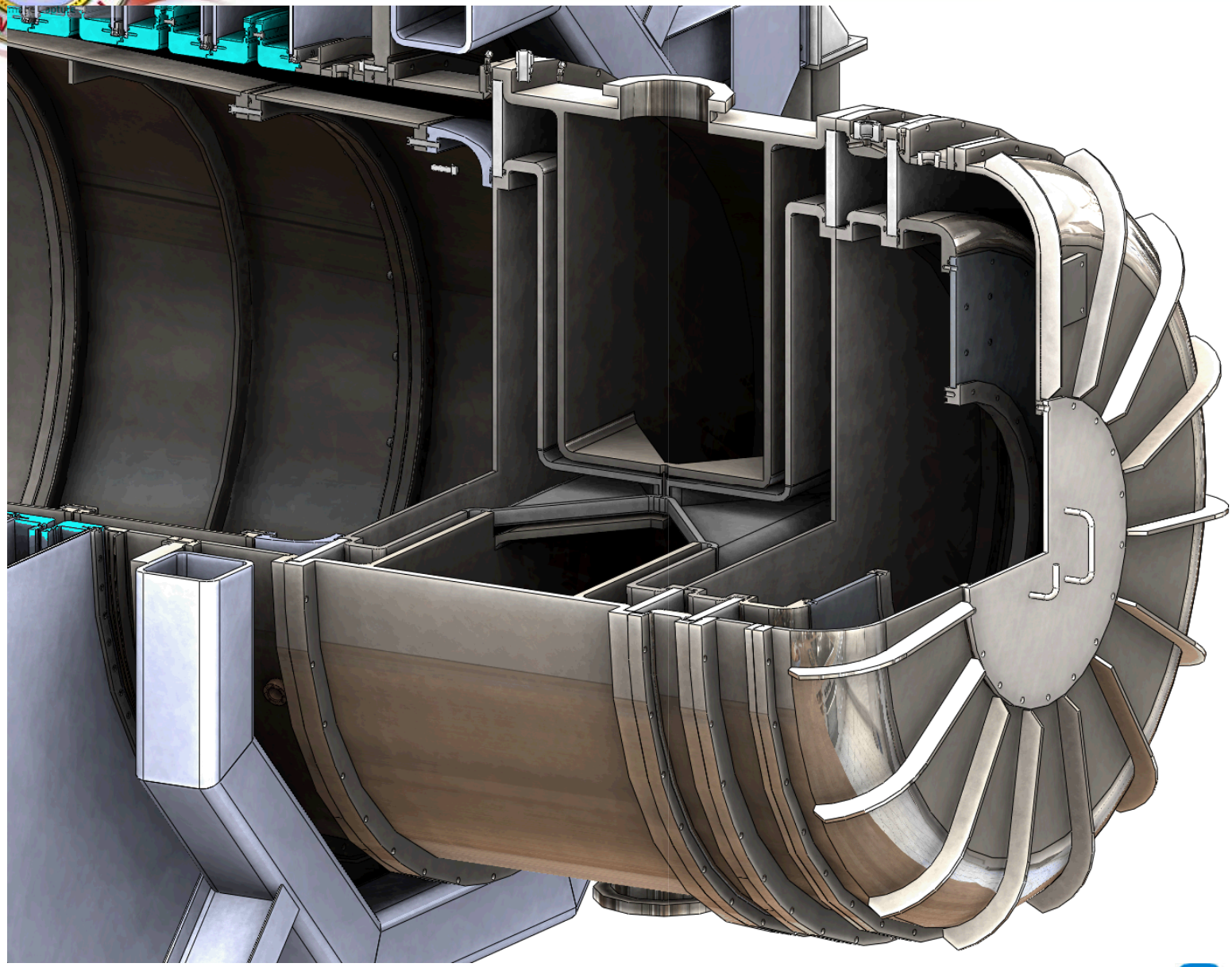
Proposed design (convolute structure).



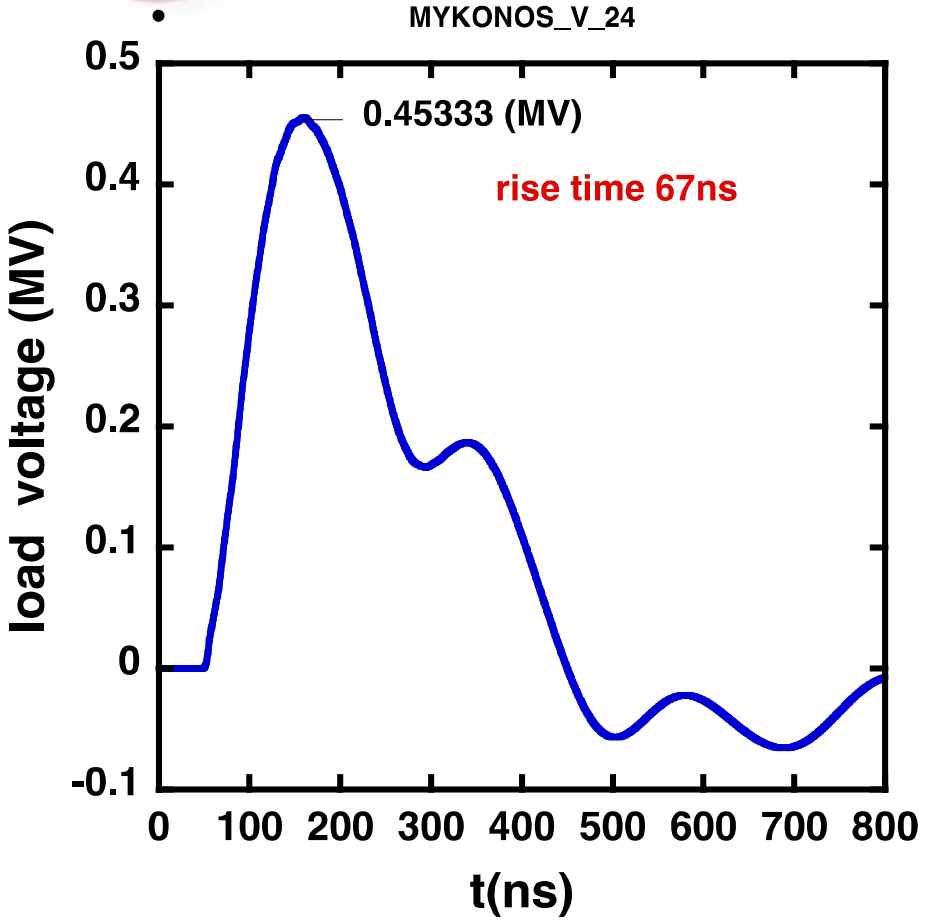
Three- dimensional view of the proposed design.

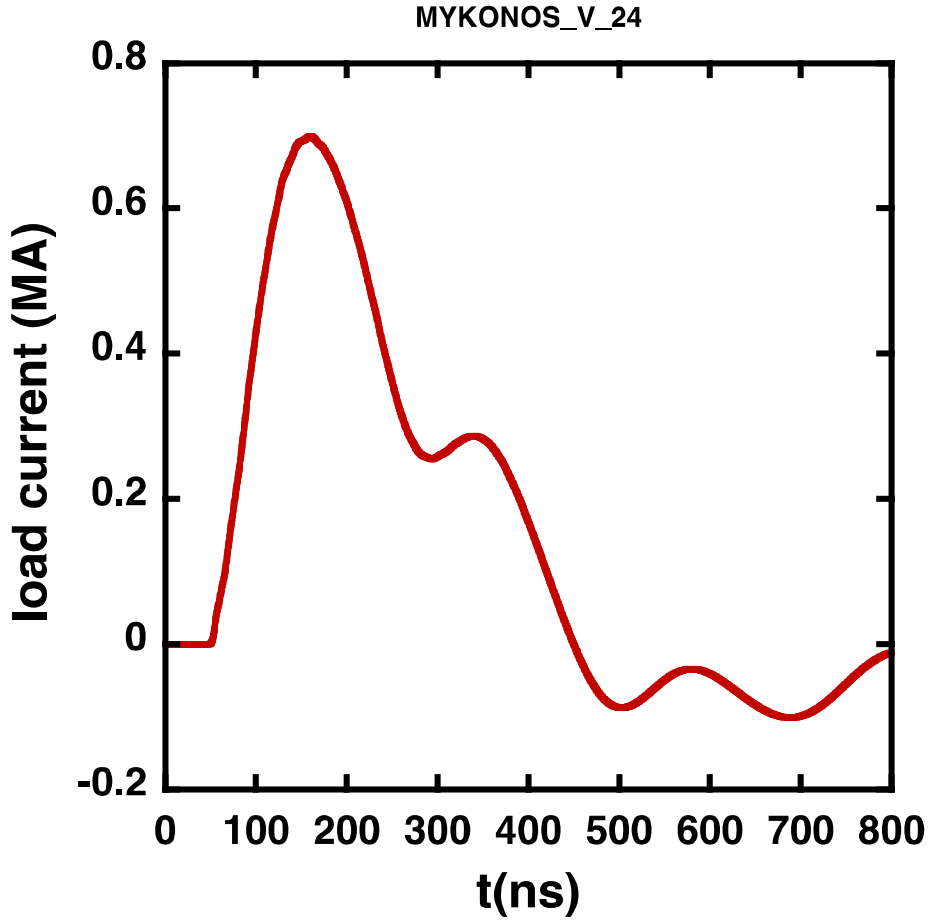


Advantages of the selected design.

- It has low load inductance 0f 3 nH.
- Offers high visibility of the convolute from outside of the vacuum chamber.
- It is enclosed in a ~ 60 cm long cylindrical vacuum chamber with many viewing windows.
- The load is already designed, manufactured and tested with MYKONOS-II.
- No substantial reflections to overvoltage the caps.

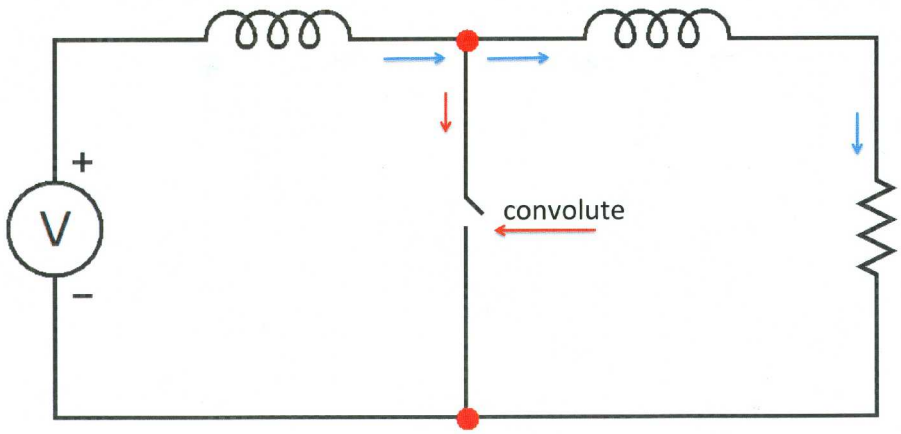
Estimated load voltage and current assuming no convolute current losses.

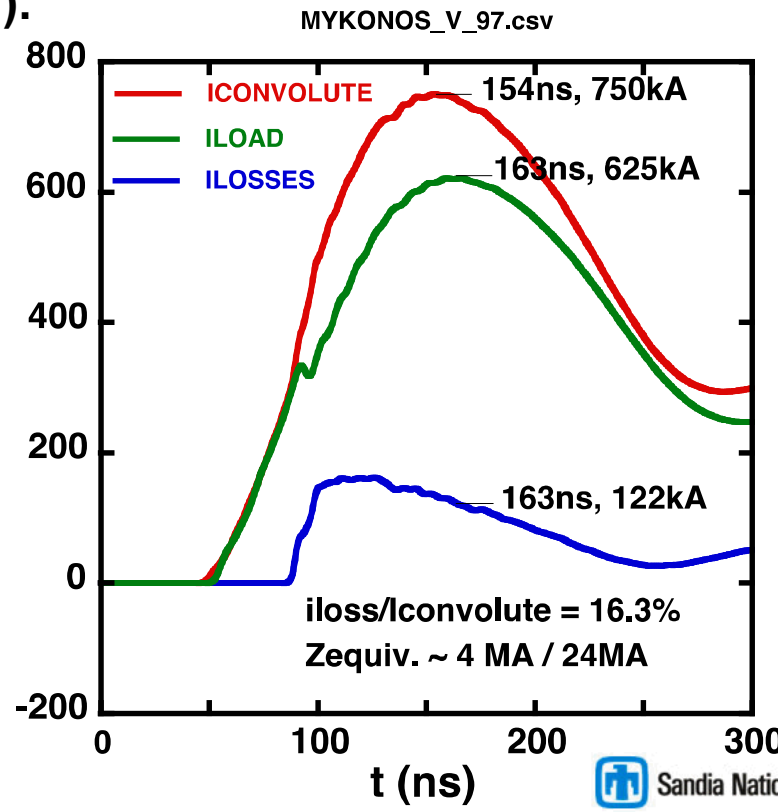




Simulated convolute losses

- To simulate the convolute current losses we included in the circuit a variable closing resistor to the ground.
- The closed resistor value was selected to reproduce the same percentage of peak current losses as the z-convolute losses (~16%).
- We turned on the decaying resistor at 90ns. This is the time in the pulse when the voltage pulse reaches 300 kV, and expect electron emission is expected in the transmission lines before and past the convolute.(~300 kV/cm).





Comparison of MYKONOS-V and Z convolute parameters.

	MYK.-V	Z
Magnetic field on post surface	55 T	38T
Magnetic field on hole surface	28 T	15.6 T
Electric field on the post surface	2.6 MV/cm	2.8 MV/cm
Electric field on the hole surface	1.3 MV/cm	1.17 MV/cm
Current density around cathode hole	0.35 MA/cm	0.54 MA/cm
Voltage	0.45 MV	~2MV
current	0.7 MA	1.5 MA
Convolute impedance	5 Ω	
Convolute inductance	5 nH	

Proposed experimental measurements.

- First stage of experimentation (measure current losses).
  - Vary hole diameter of the post-hole convolute.
  - Measure losses upstream and downstream of the convolute.
  - Observe plasma formation light emission with a single frame digital camera (open shutter).
  - Analyze spectroscopically emitted light (use fibers connected to a Z available spectrograph.
- Study means to mitigate current losses.
  - Increase the temperature of the convolutes by multi-pulsing and or heating tapes.
  - RF cleaning.
  - Study vacuum effect on losses.
- Evaluate location of plasma emission.
  - Selectively coat areas of cathode hole surface with dopants.

Summary and future plans.

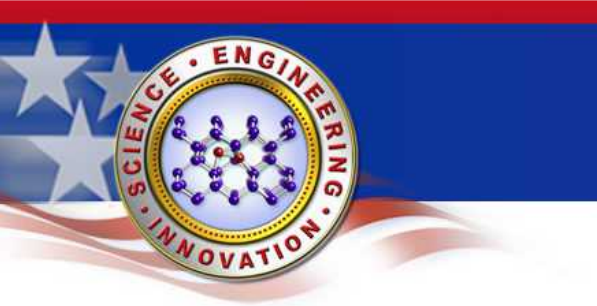
- The MYKONOS V selected convolute experimental set-up is designed in such a way in order to reach conditions on the convolute very similar to those existing on one of the Z post-hole convolutes.

- Most importantly, in contrast to Z, it provides full view of the convolute for optical and spectroscopic imaging from the outside of the vacuum chamber.

- It gives the flexibility and freedom to try and study various options in an effort to reduce the convolute losses without affecting the day- to-day Z experiments.

- We can fire many shots without breaking vacuum to replace targets. From those we can collect a lot of data in a relative short time of experimentation.

- Applied lesson learned to Z.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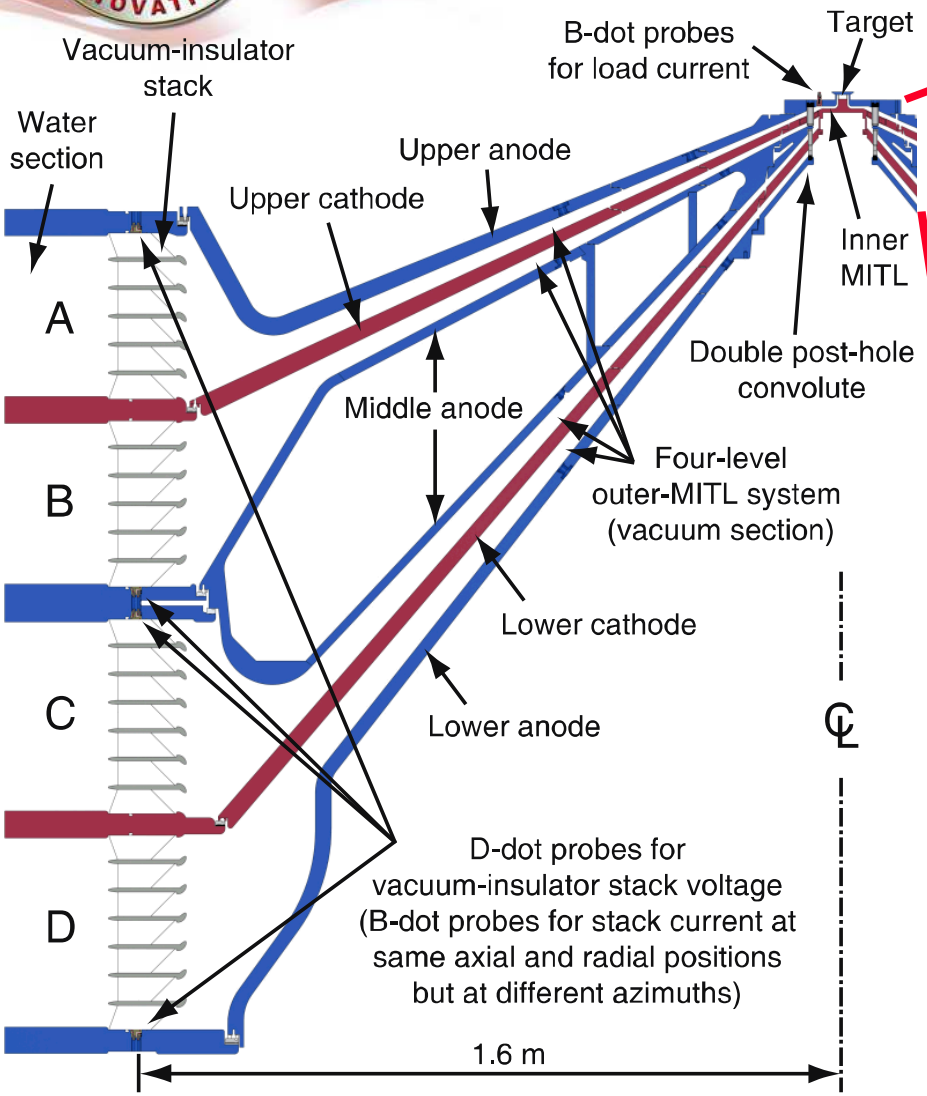
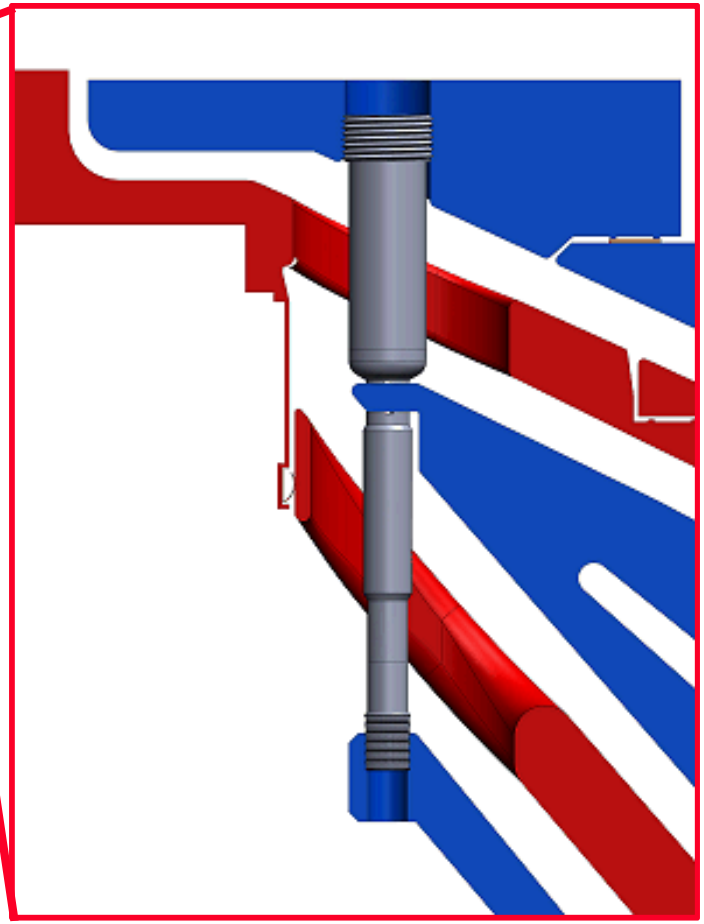
Side section of Z vacuum area and convolutes.



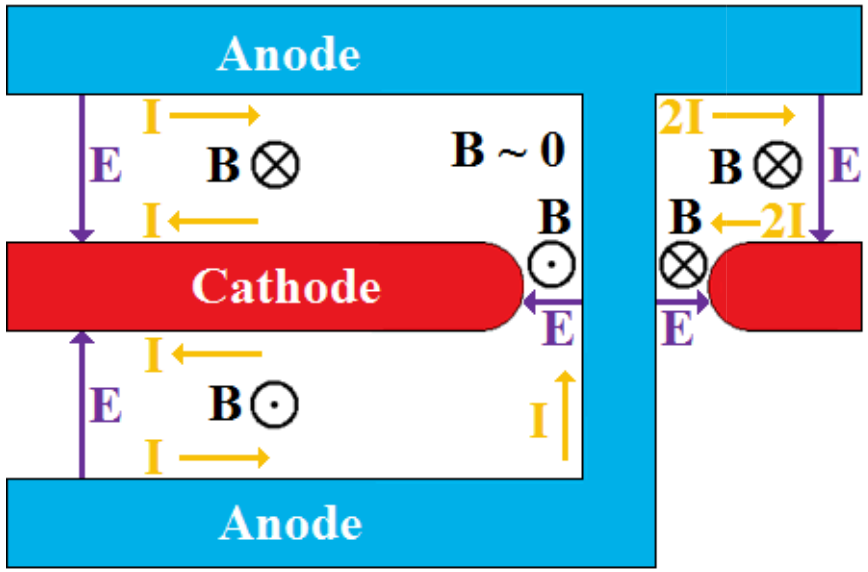
Z vacuum section



convolute section

A simple one post-hole convolute converts a trip-late strip-line to a bi-plate one.

- The bi-plate transmission line current in principle is equal to the sum of the two halves of the tri-plate.



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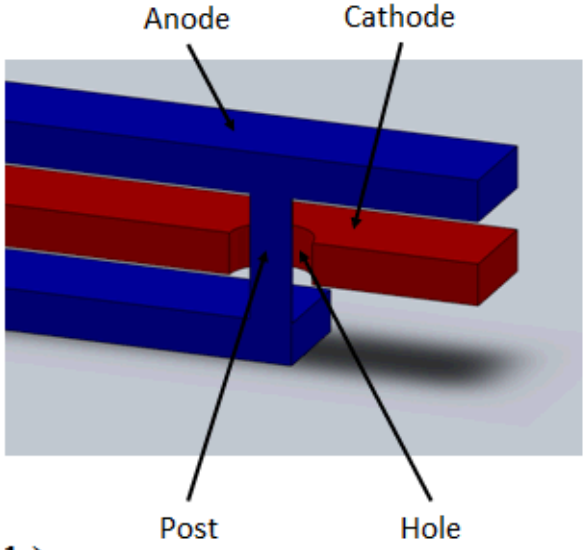

b)

Matthew R. Gomez, PhD Theses, University of Michigan 2011