Z for Beginners

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High Energy Density Physics Theory - 1641

Outline

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  - Pulse Shaping Capabilities
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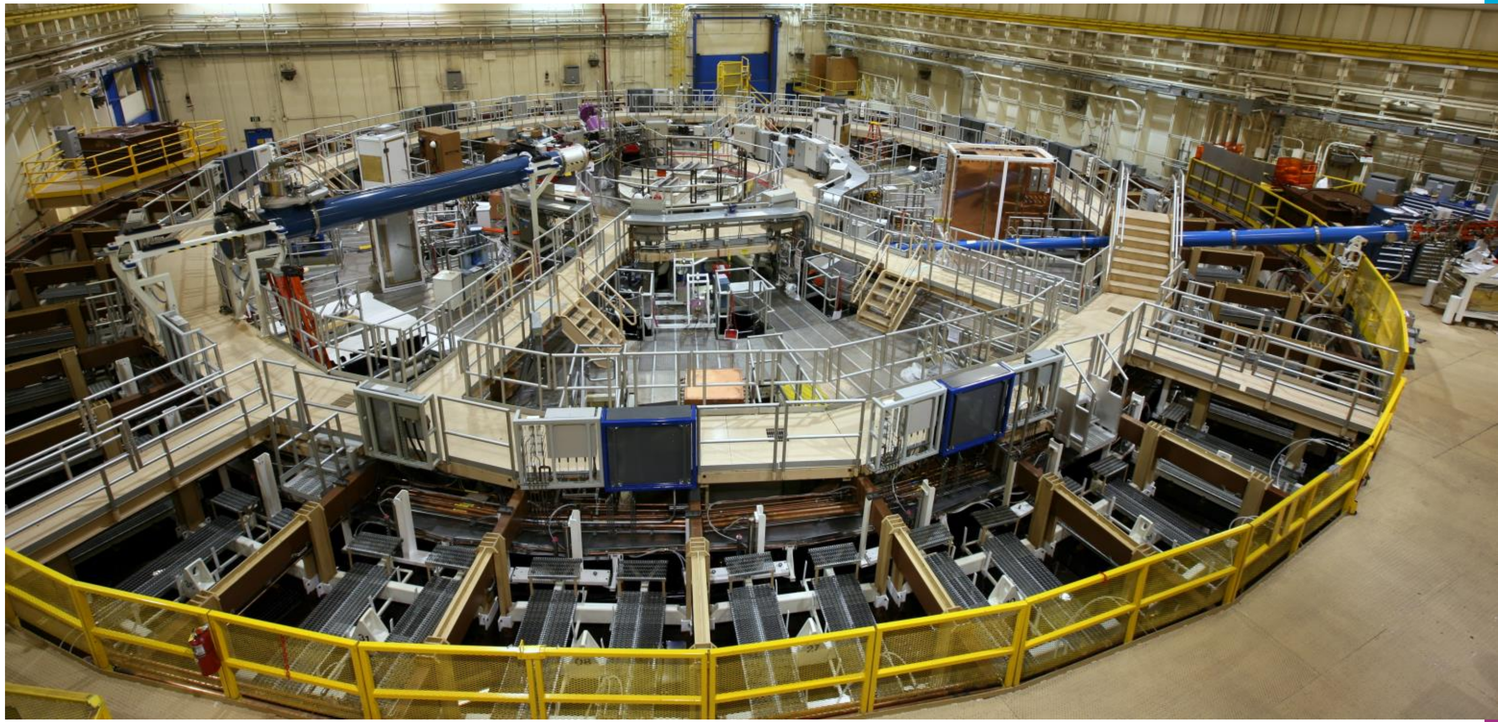
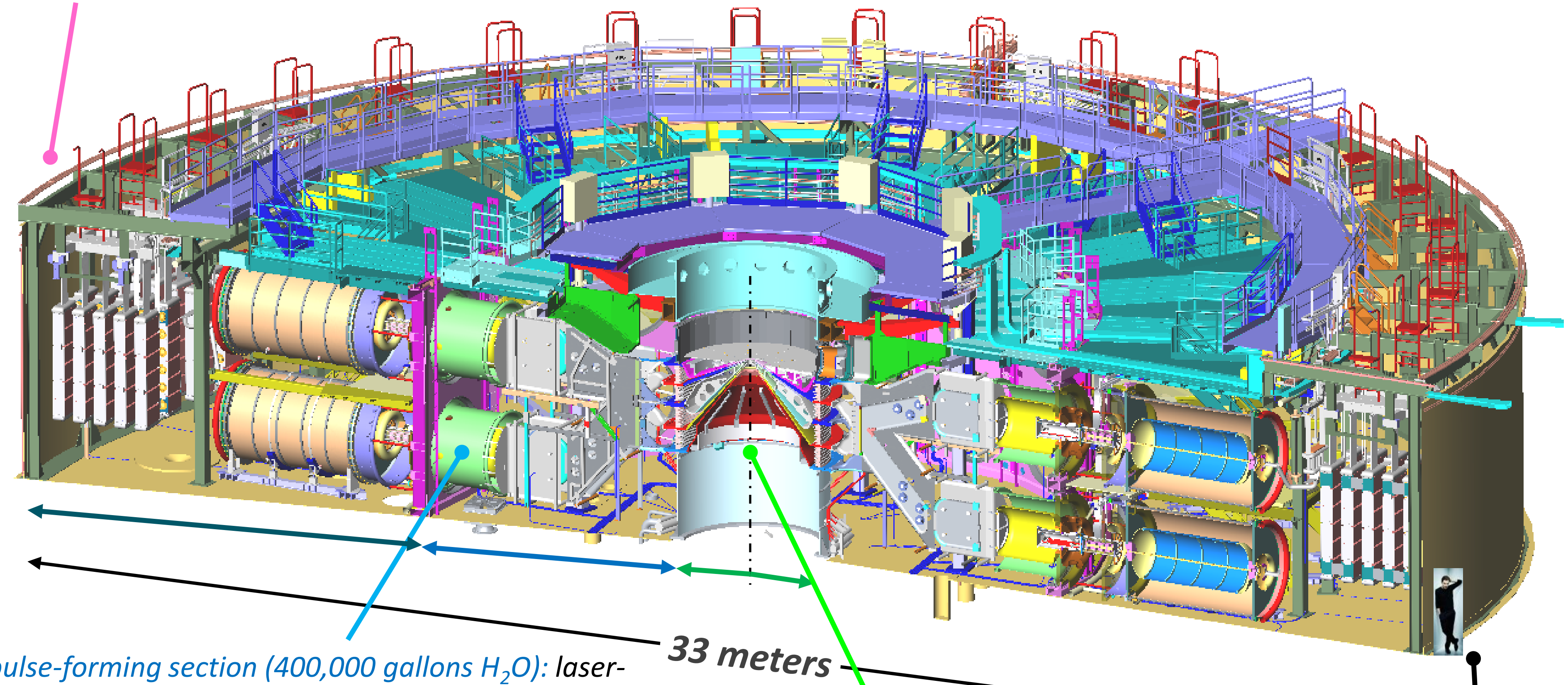


Z Machine at Sandia

energy storage section (600,000 gallons oil): stores 23 MJ in 36 banks of 60 capacitors (each 2.3 μF), charged in parallel (90 kV), discharged in series (5.4 MV)

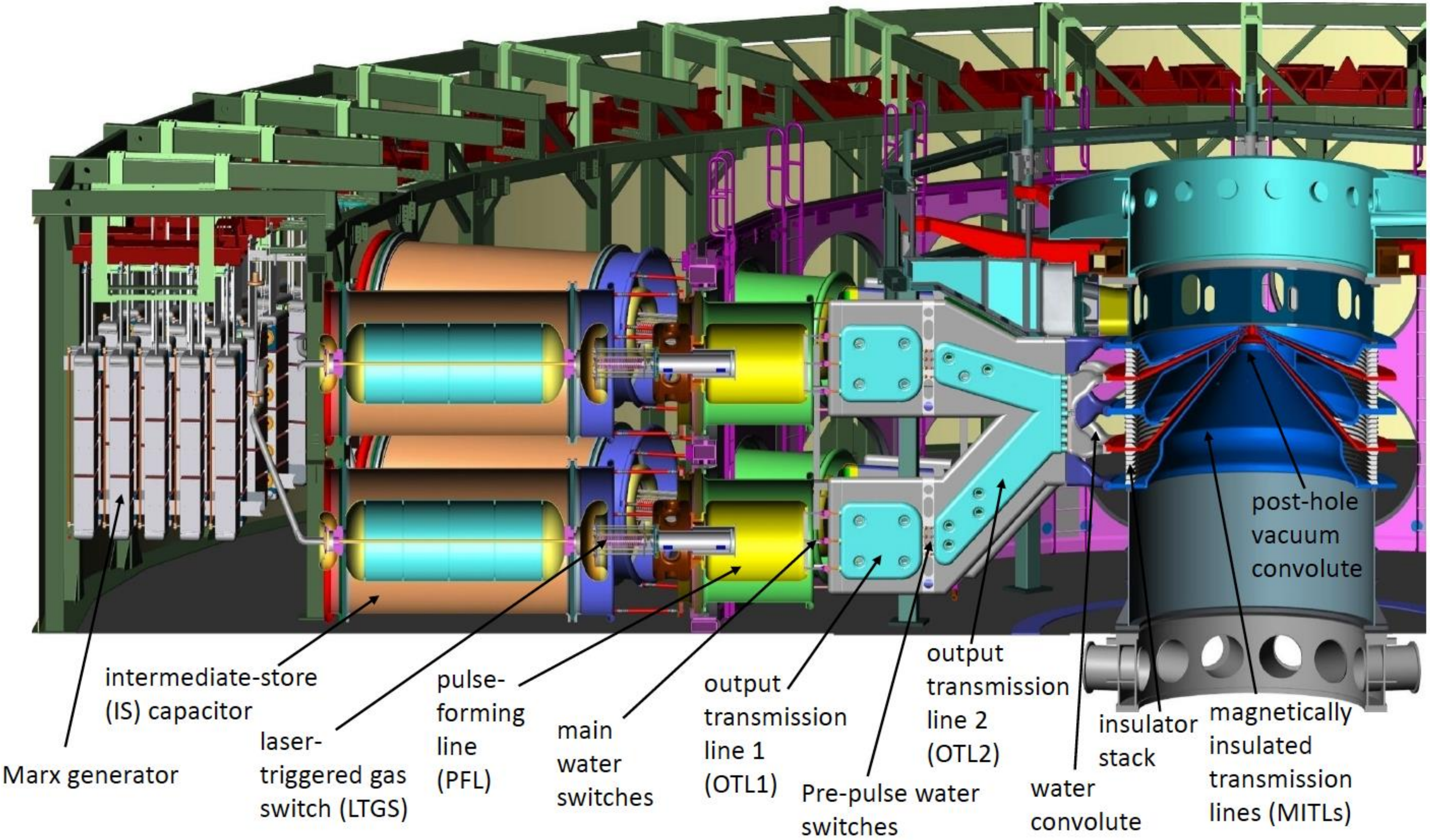


pulse-forming section (400,000 gallons H_2O): laser-triggered SF_6 gas switches & H_20 spark-gap switches compress pulse to 100-1500 ns rise time, tri-plates reduce 36 lines to 18, convolute reduces further to 4 radial feed gaps

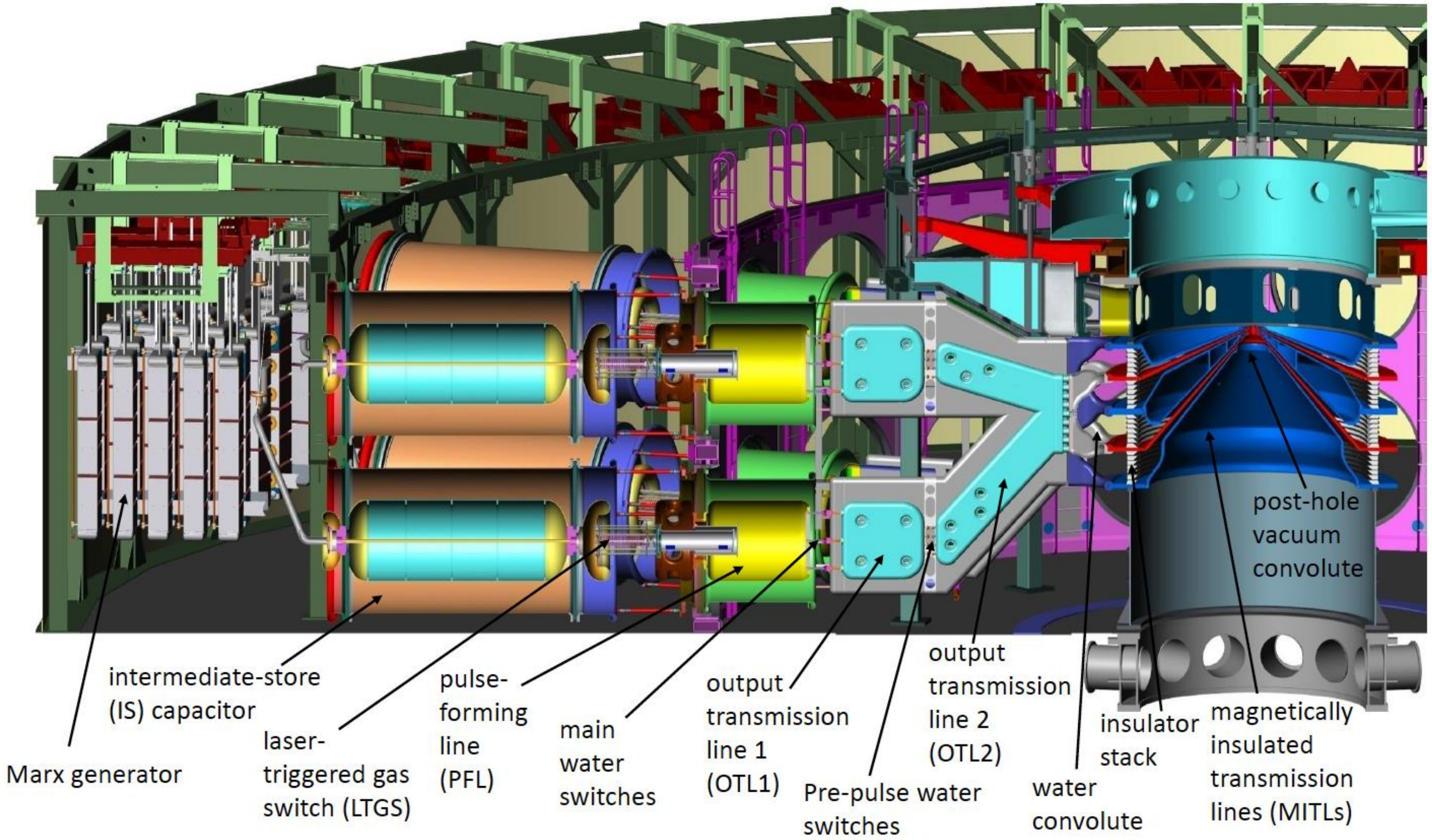
center section (10^{-5} torr vacuum): ***magnetically insulated transmission lines (MITLs) deliver up to 26 MA to the load; convolute reduces 4 feed gaps to 1***

Cumberbatch
for scale

Pulse Forming Section



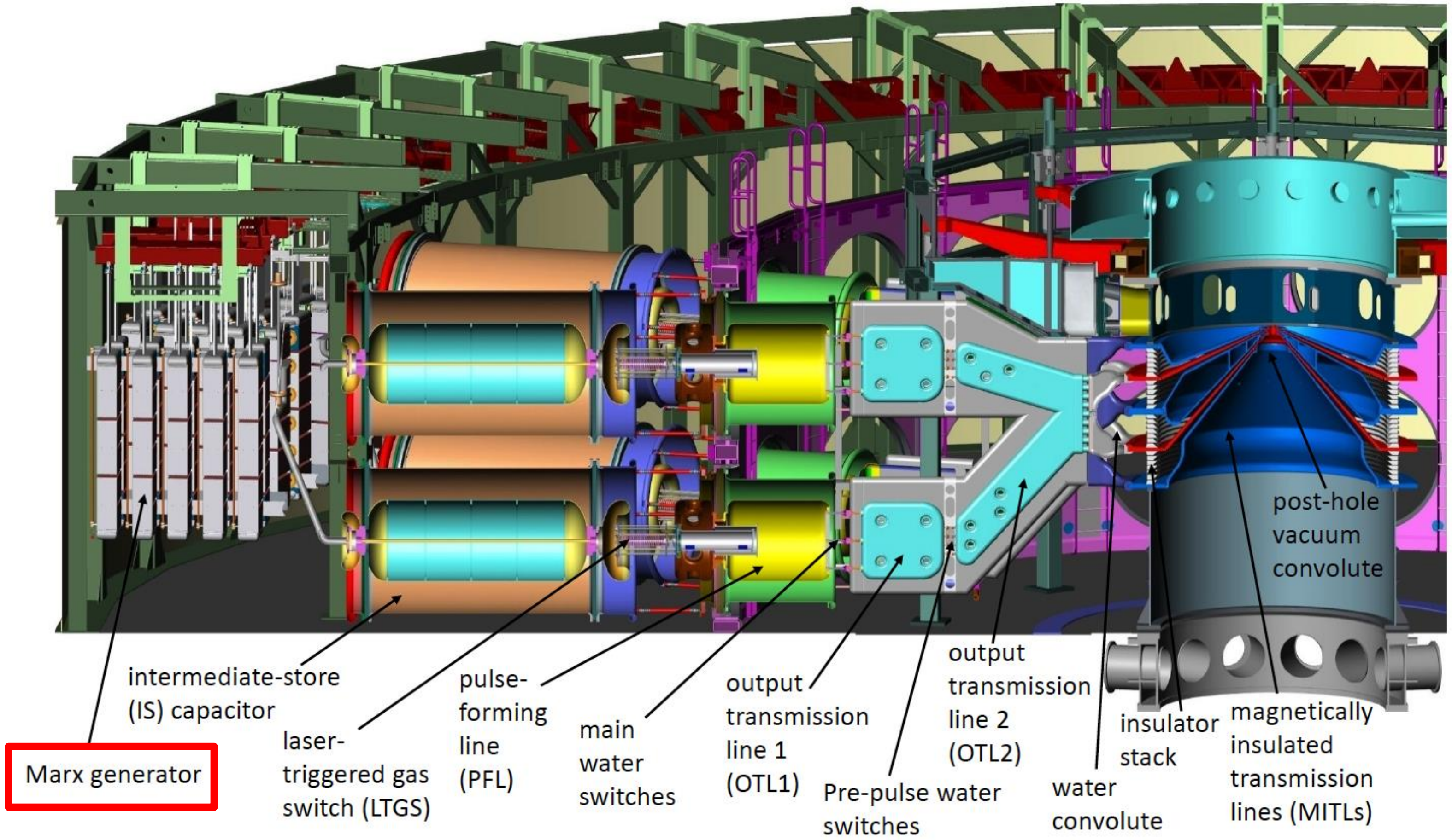
Pulse Forming Capabilities



The quantum of Z is one of the 36 lines in the pulse forming section (18 upper and 18 lower).

Each of the 36 lines can be set to an individual pulse shape. At present, no finer control exists. There are some pulse shapes that are not possible to obtain on Z. Determining if a pulse shape is possible in a complicated and largely intuitive process.

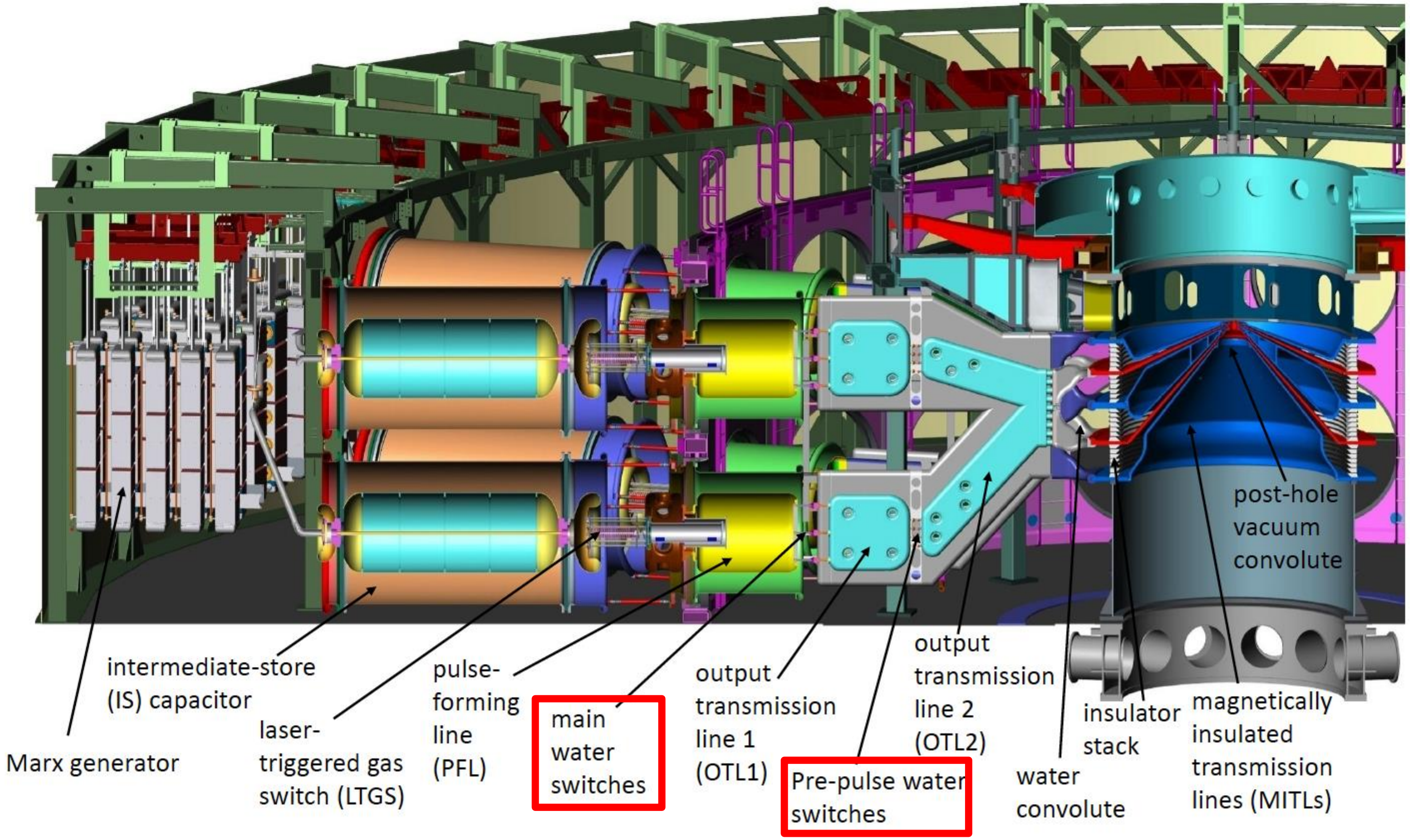
Marx Charge



The primary lever arm on Z is the Marx charge. This controls the total energy available on a given shot. Each of the 36 lines of Z are set to the same Marx charge, though a line can be disconnected ("bussed out").

Nominal values: 55-85 kV, 95 kV under some circumstances

Pulse Shapes



Z pulse shapes are selected by modifying the main and pre-pulse water switch gap spacings. These are conventional spark gap switches.

Nominal values: 5 standard pulse types, though hybrids can be created through advanced pulse shaping.

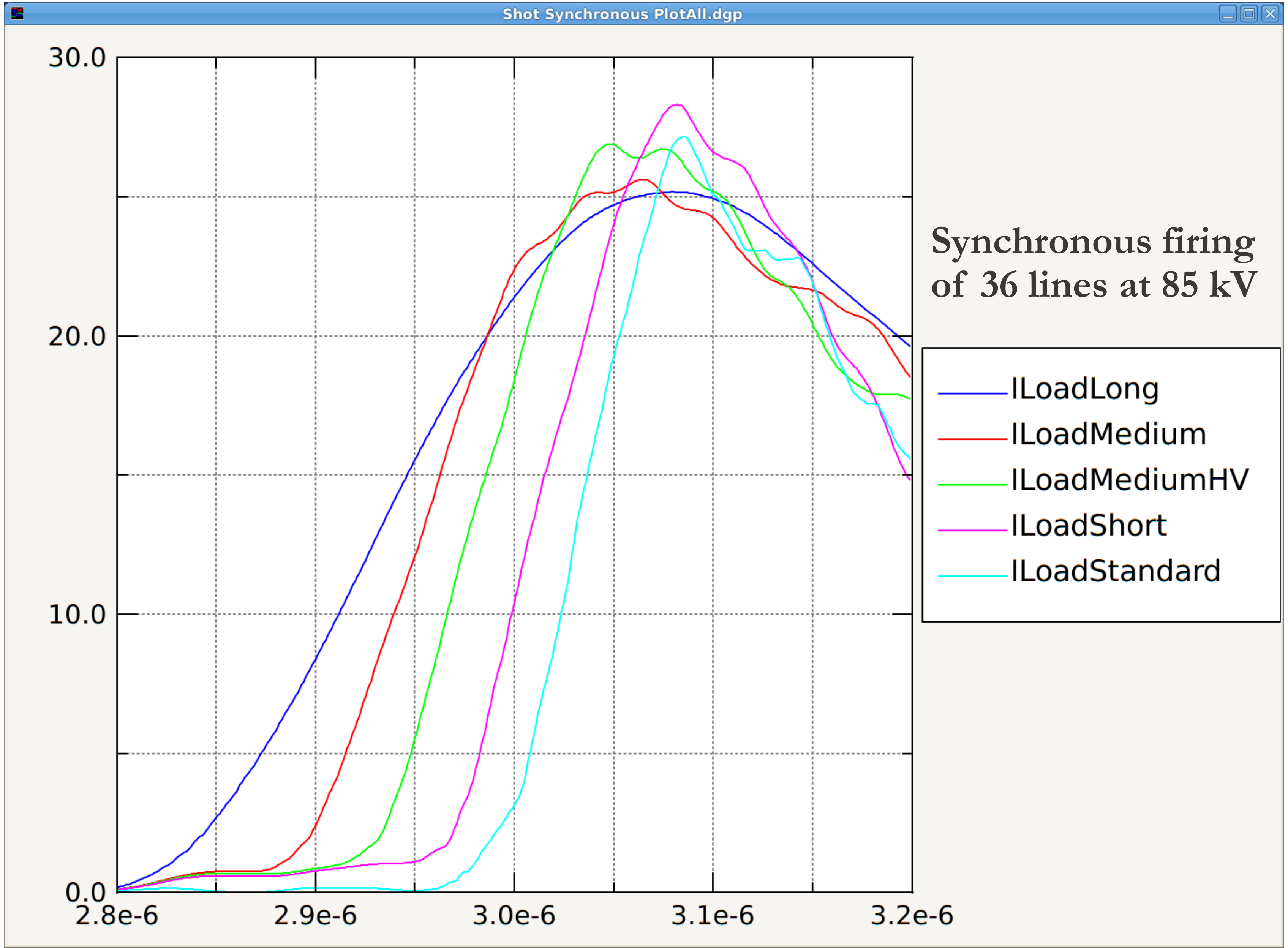
Standard Pulse Shapes

Natural rise times range from 100 ns to 300 ns.

Combining up to 36 of these shapes to obtain a desired current profile is called **"pulse shaping"** and is a specialized task.

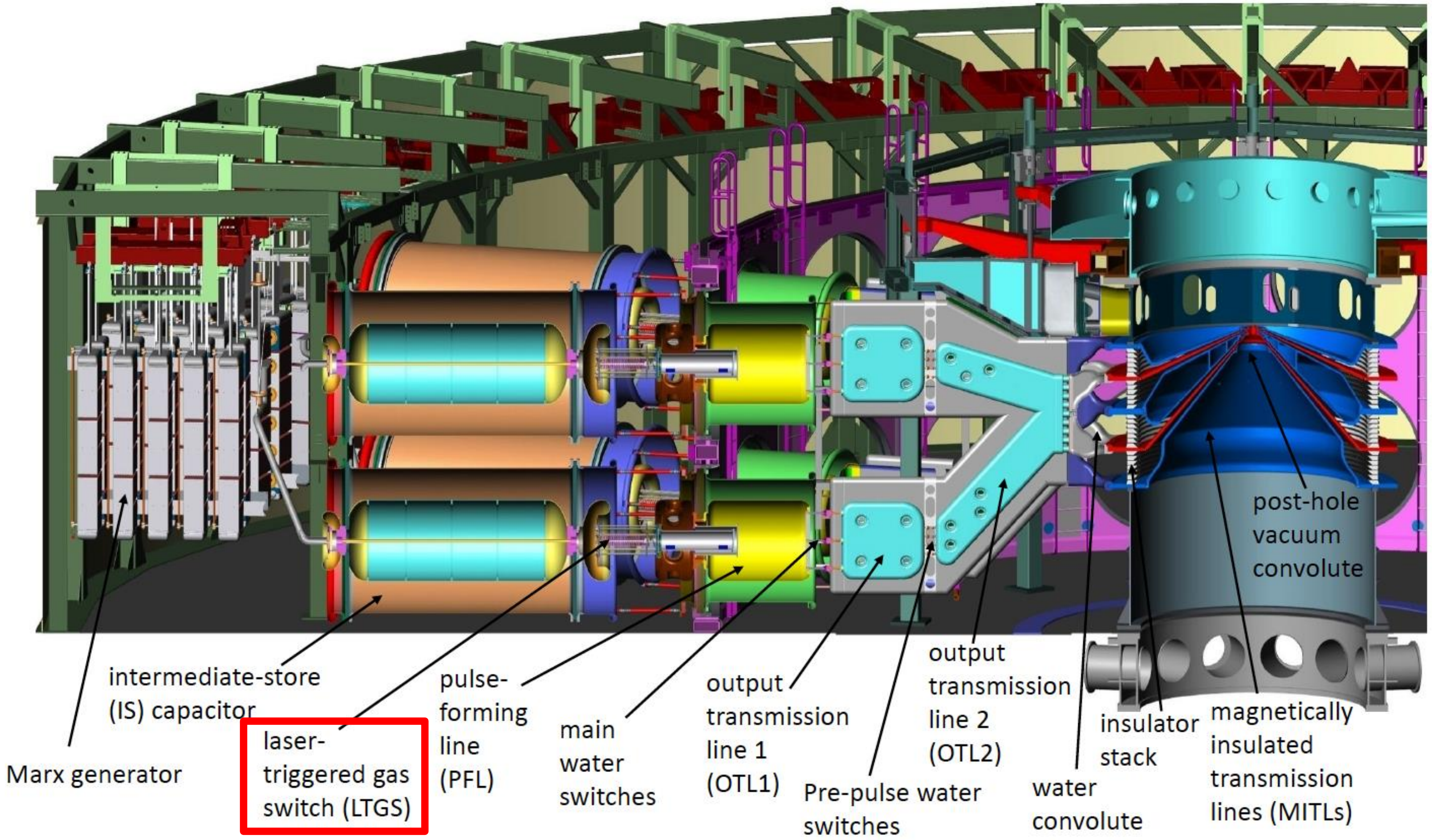
Each Z shot requires a **"designer"** to accomplish this task.

Some PIs are also designers.



Synchronous firing of 36 lines at 85 kV

Laser-Triggered Gas Switches

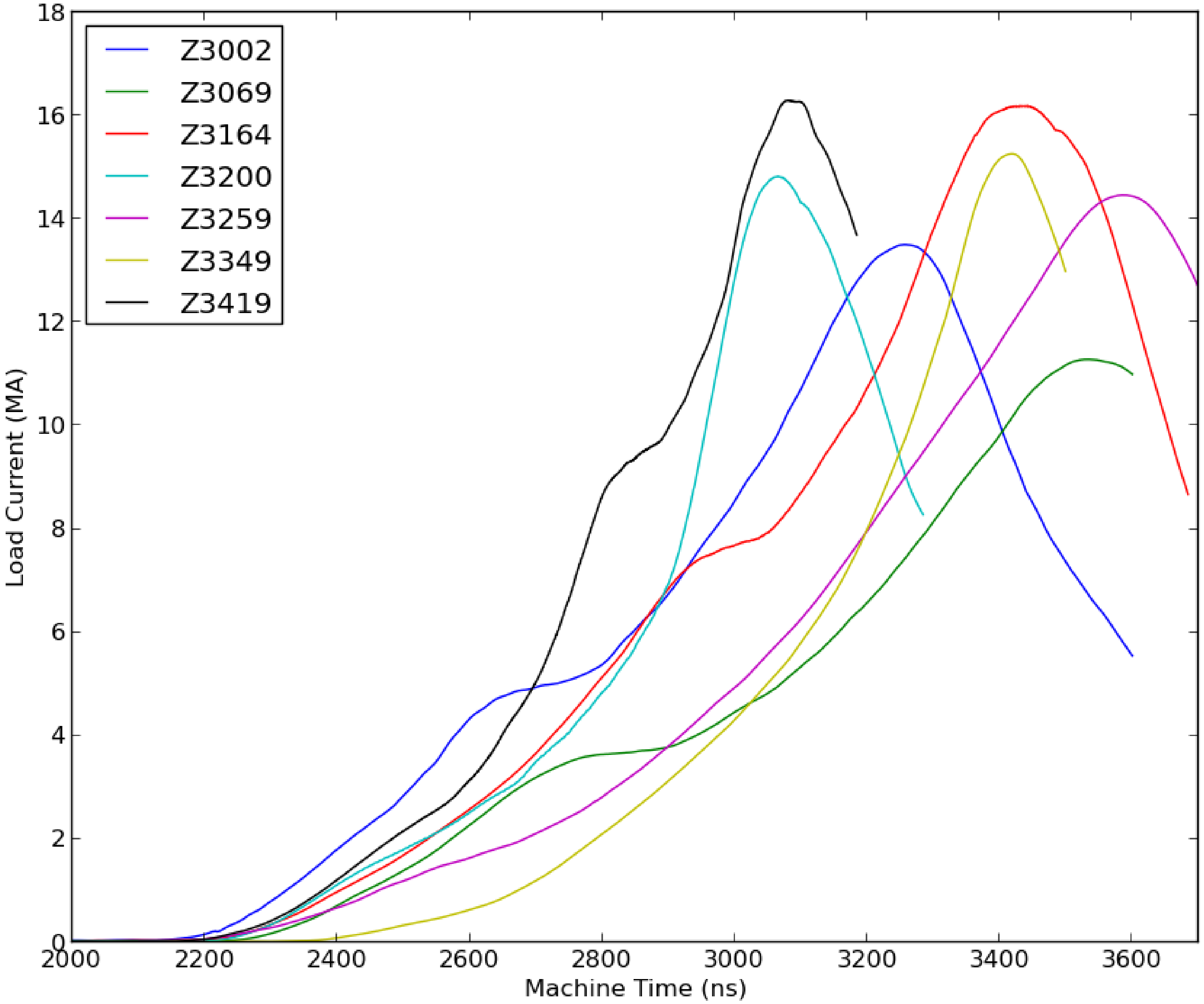


Individual lines can be staggered in time using the LTGS.

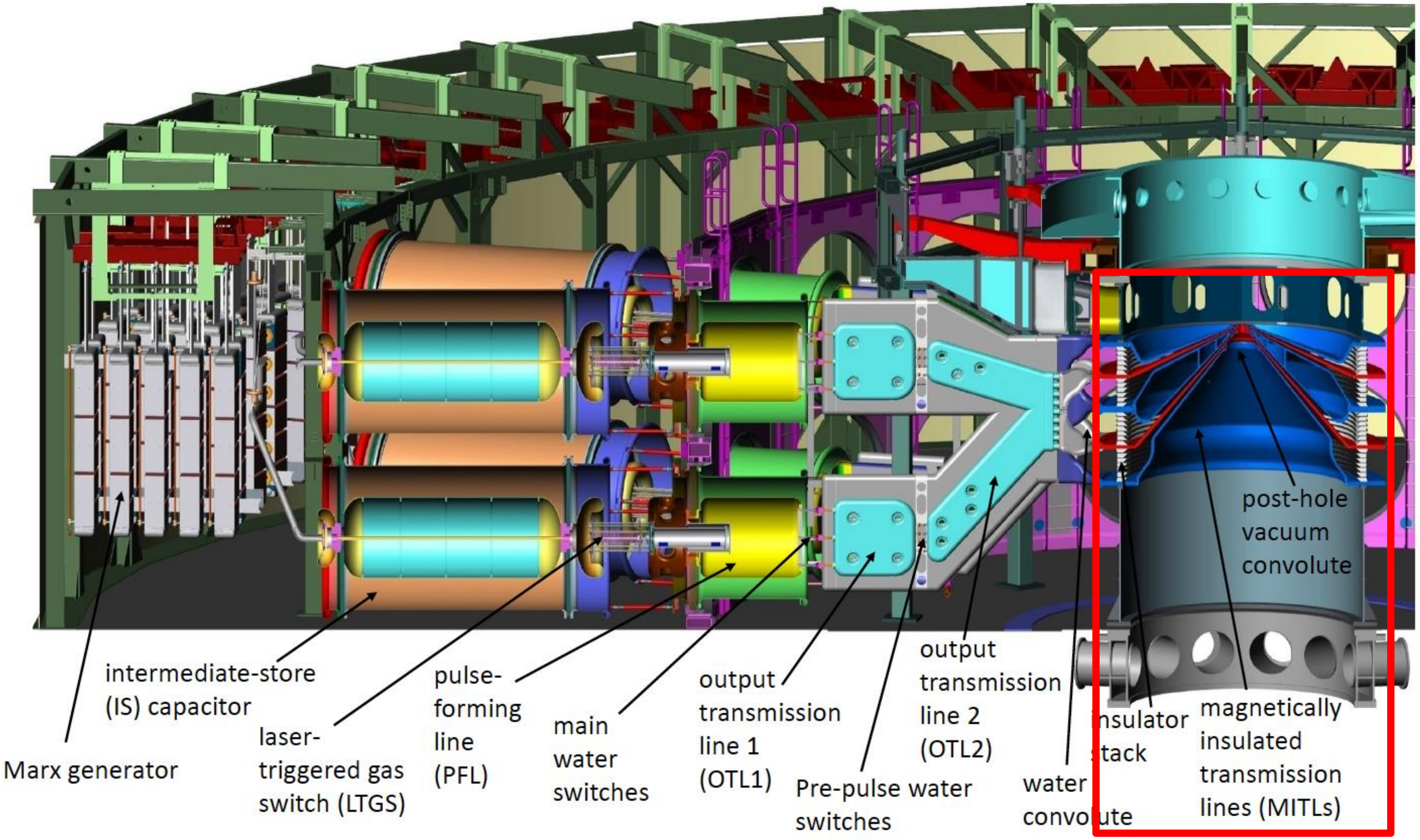
Nominal advance times: +600, -250 ns

Select subsets of Marx can be fired on a delay, increasing the possible current rise time to ~1500 ns.

Example Pulse Shapes (Ramps and Shock-Ramps)



Vacuum Section

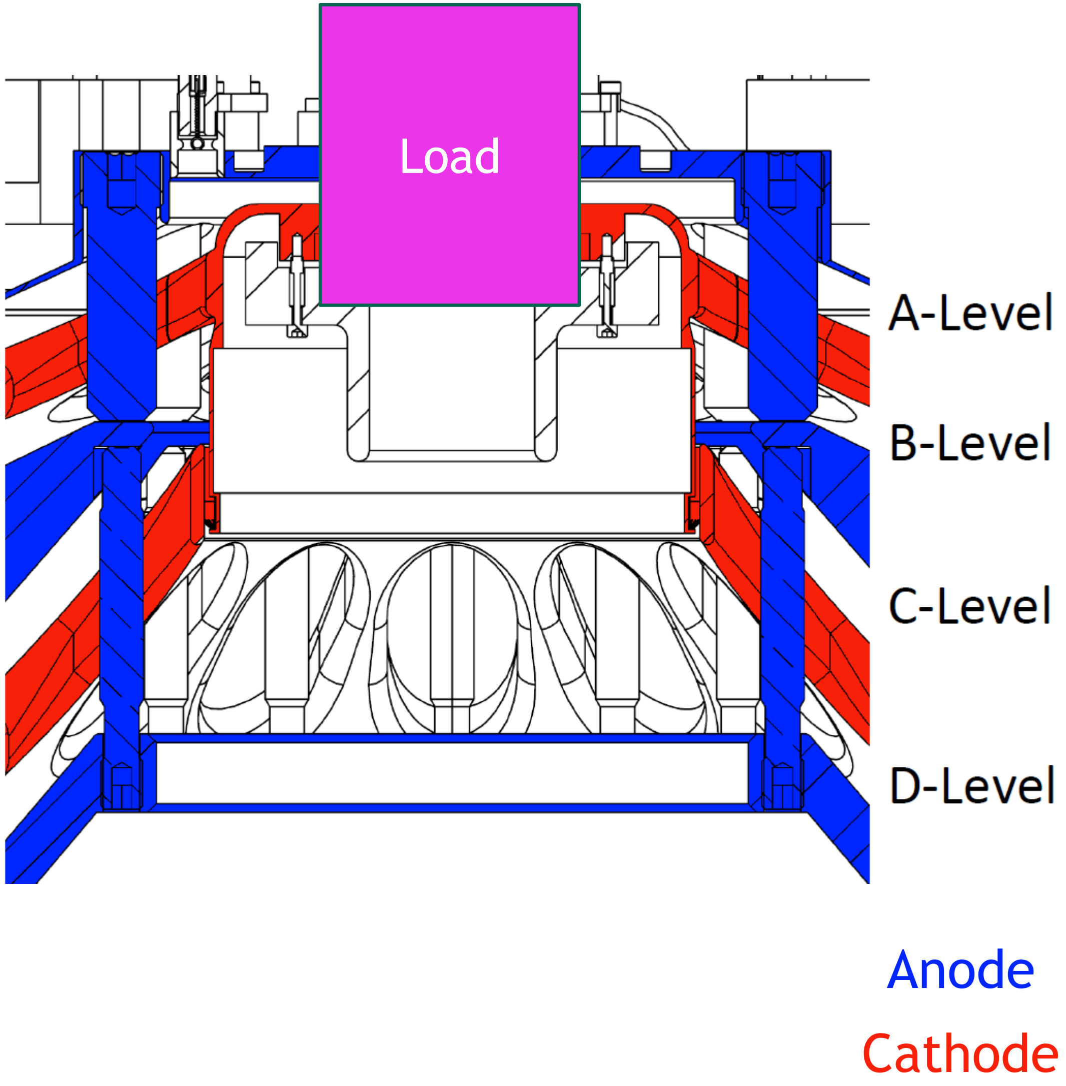


The MITLs extend from the wall of the vacuum section (the "Stack") to the middle of "Center" section where the load (experiment) is placed. The MITLs deliver current to the physics experiment.

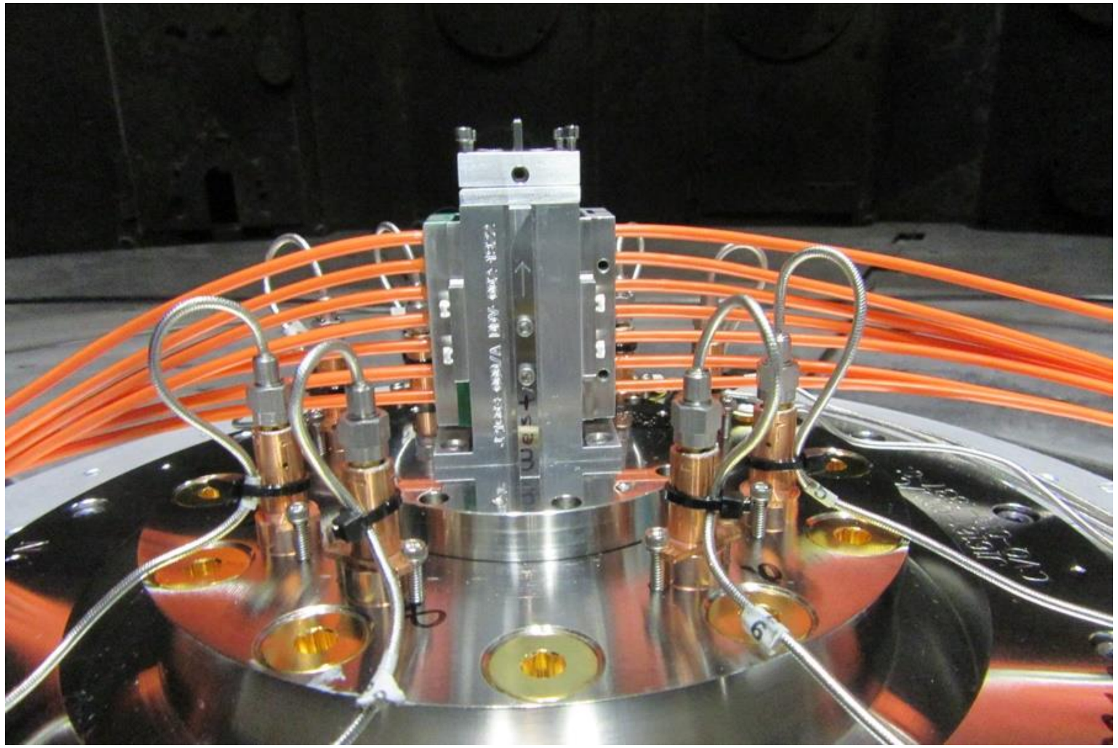
Center section is ~ 3 meters in diameter and is a beryllium contamination zone. Only specially trained personnel are allowed inside.

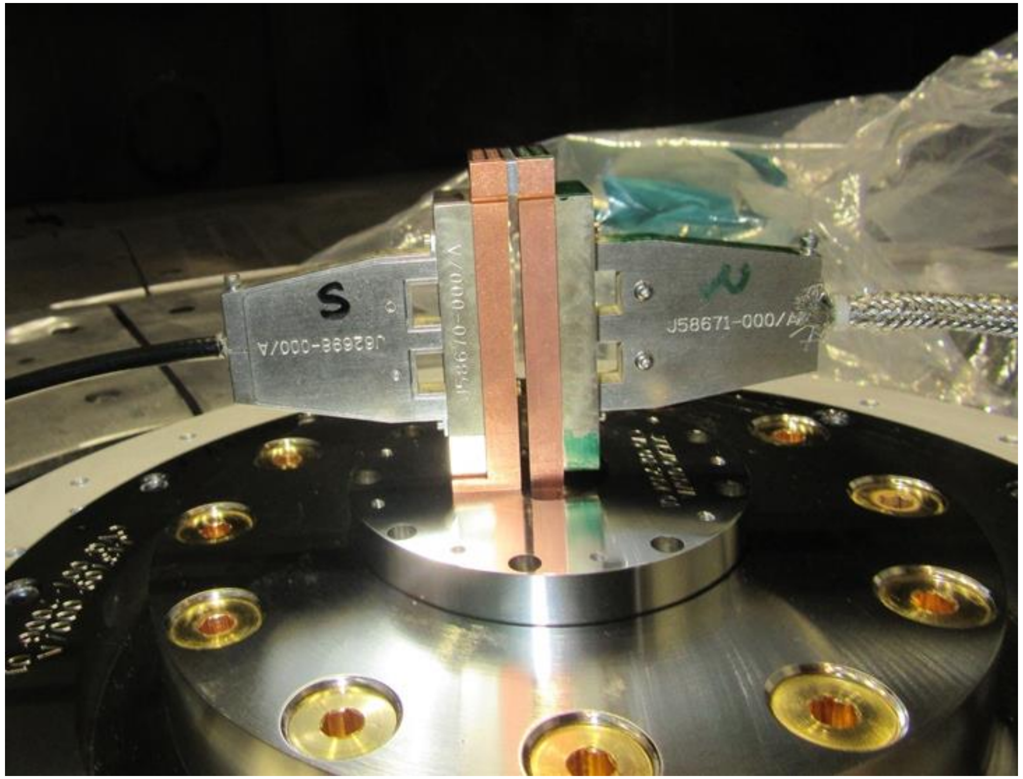
Convolute Power Flow

- Z convolute combines the four MITL levels into a single power flow gap.
- Magnetic nulls are formed around the convolute posts, potentially allowing charged particles to escape the magnetic insulation. **This can result in meaningful current loss.**
- DMP targets compress materials by opening a power flow gap, this results in an increase in load electrical inductance.
- Convolute loss is triggered if the load inductance is mismatched to the driver. **Many of our DMP targets have load inductances that are significantly above what Z was designed to drive.**
- Remember that current delivery components on Z are not immune to failure. **There is a non-zero shot failure rate** due to power flow abnormalities.
- Current loss modeling is an active research project on Z.



Types of DMP Loads

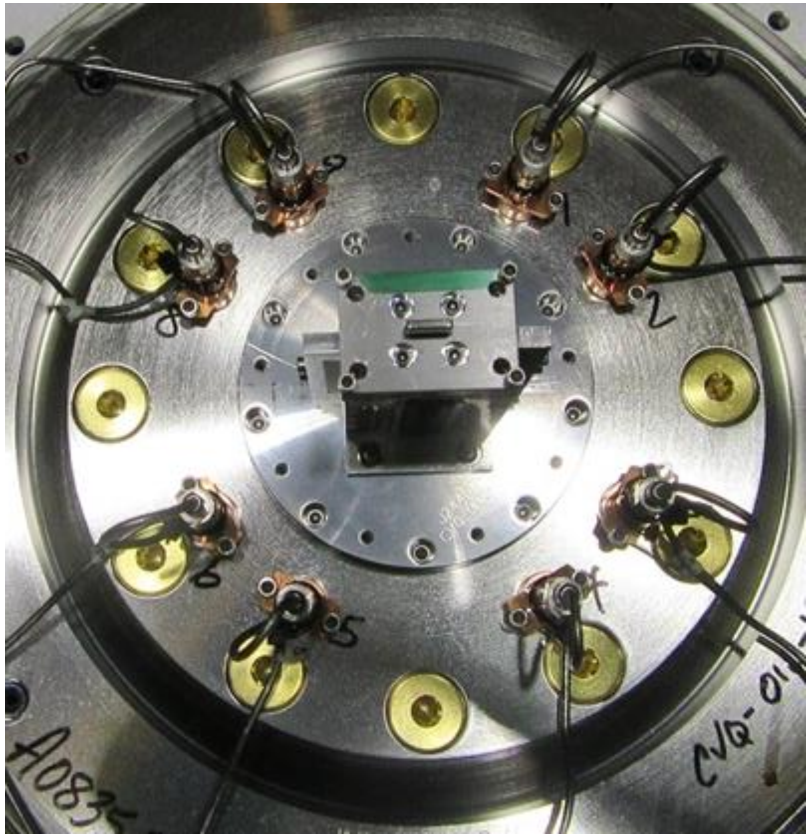


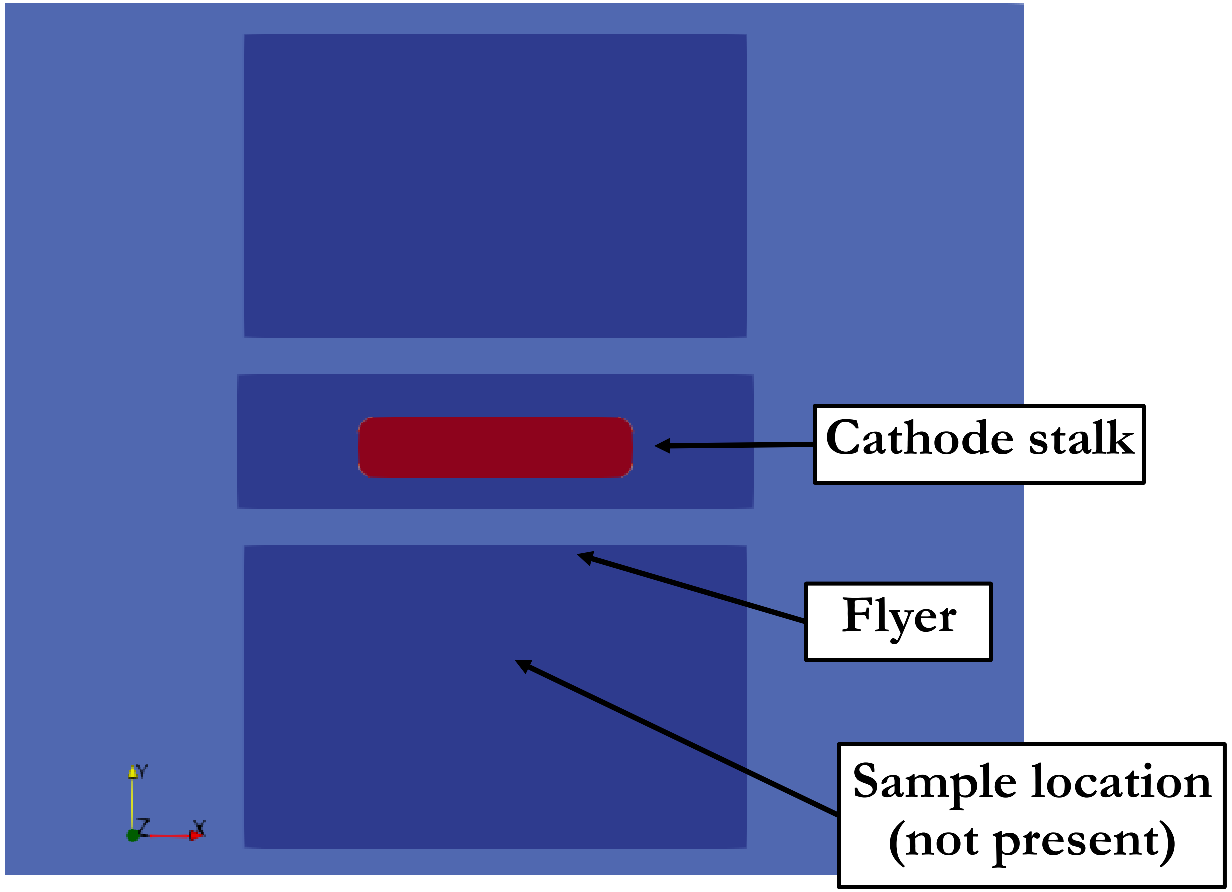


The two main Z loads for DMP are the coax and the stripline.

Both work on the same principle: strong magnetic fields exert pressure on a standard material (copper or aluminum) which mechanically couples to a target sample. The sample is magnetically insulated.

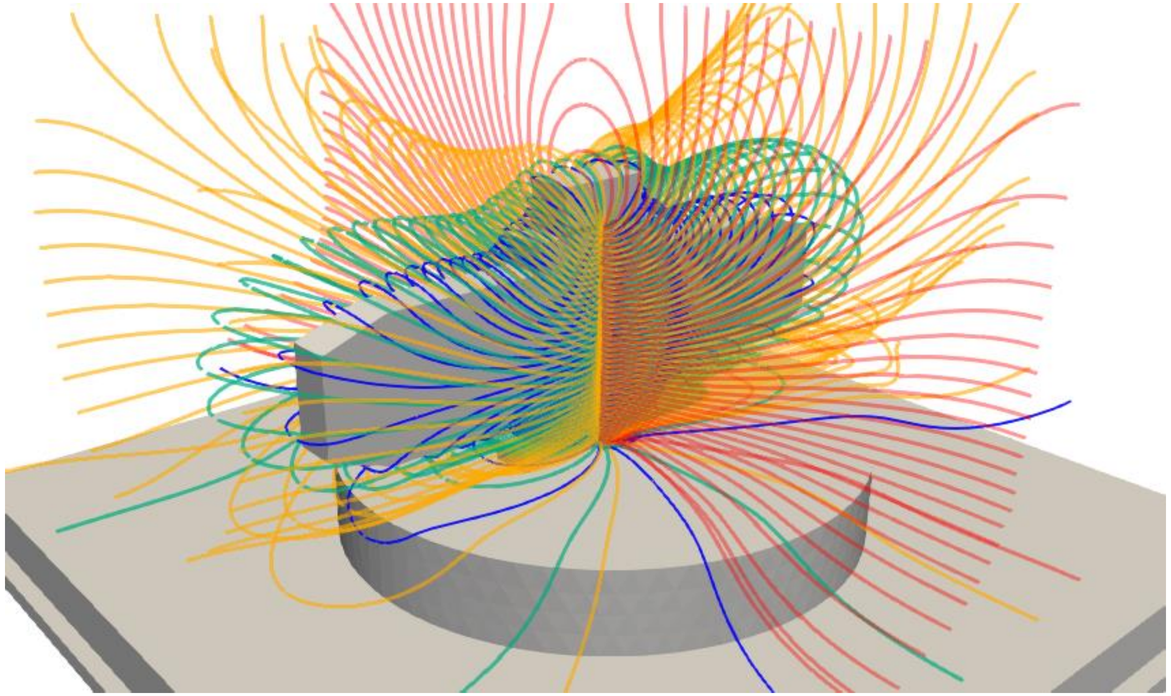
Coax (Coaxial Box)



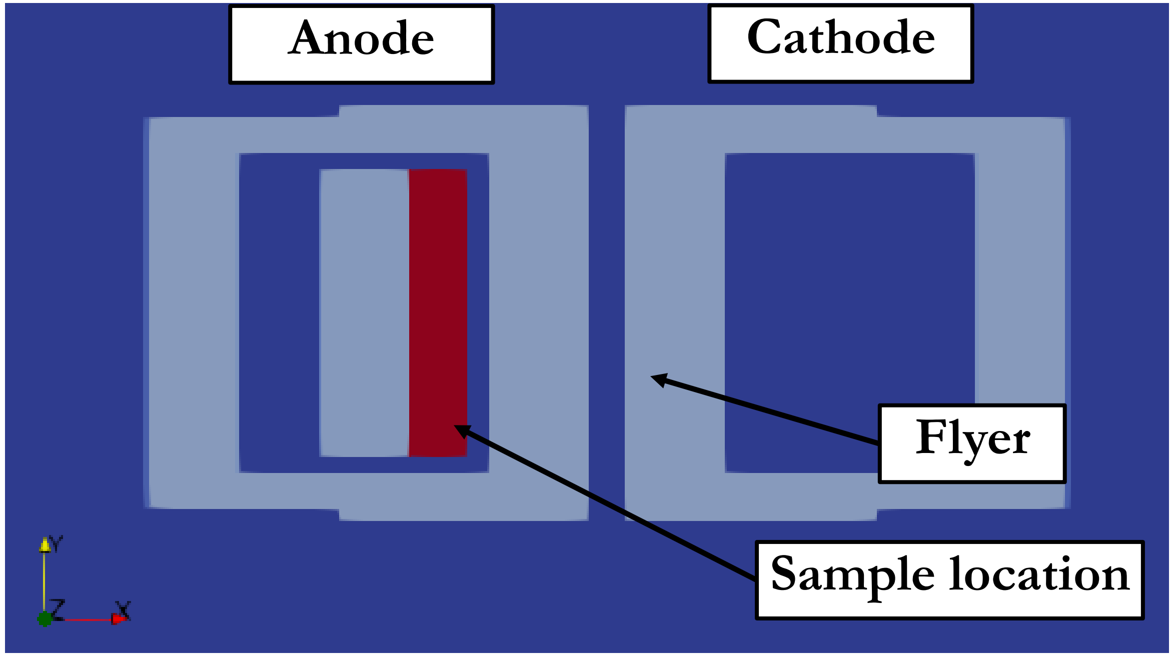


The simplest DMP platform is the coax, which electrically is a rectangular coaxial geometry. Coax is **typically used for shock (Hugoniot) experiments**, and allows for modification of flyer velocity on each side of the panel. The **magnetic field is contained**, meaning external diagnostics are largely shielded from Z's magnetic field. The change in magnetic flux volume over the experiment is small, so coax has a small dynamic inductance.

Stripline



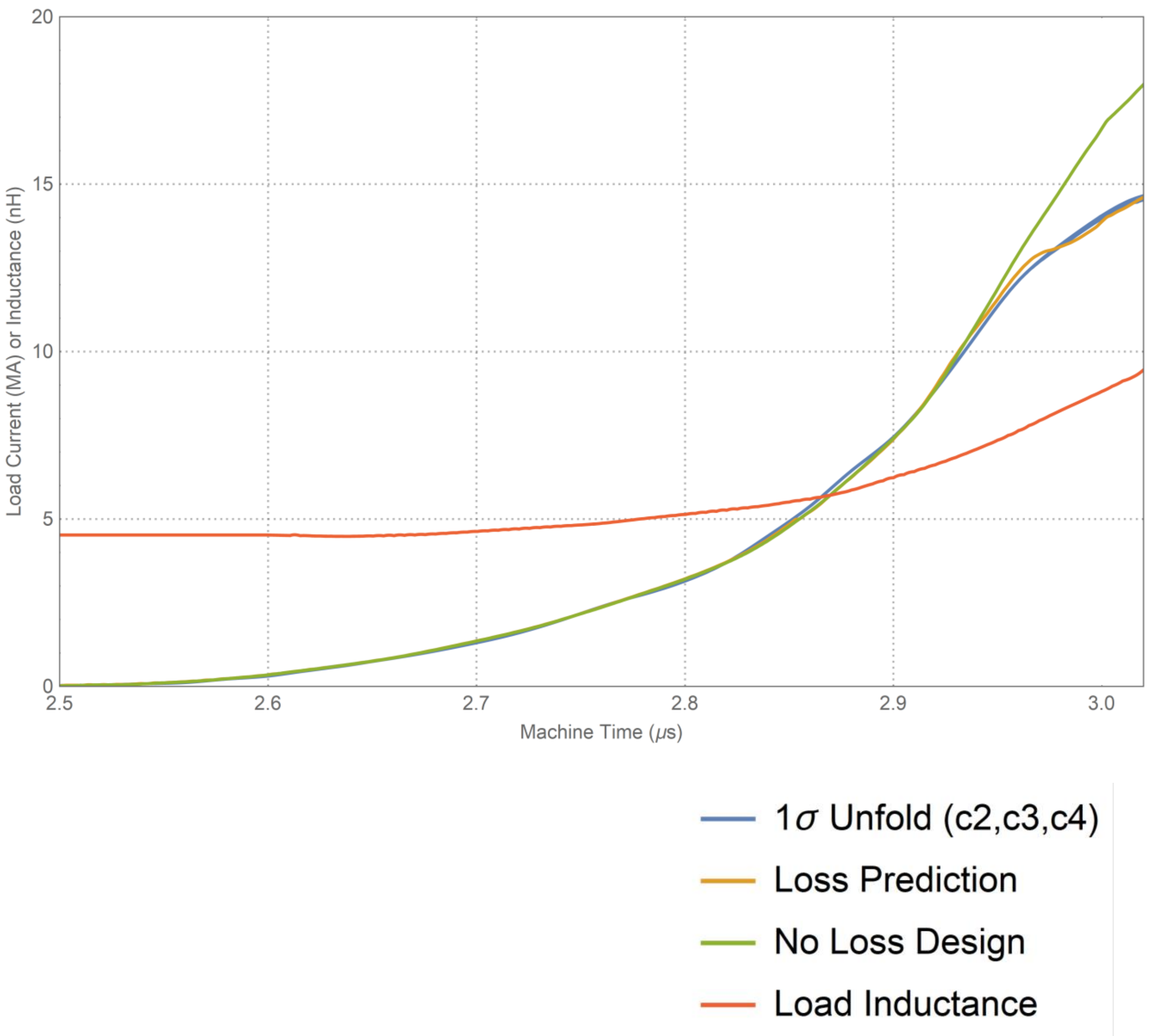
Simulation courtesy Jeremiah Boerner



The Stripline is a more efficient use of magnetic energy, thus **striplines typically reach higher pressures than coax** experiments. Striplines have higher dynamic inductances than coax, and **typically carry fewer samples** (to decrease inductance). The **magnetic field of a stripline is unconfined**, potentially exposing external diagnostics to signal interference if not shielded properly. Additionally, there is a direct line of sight to the power feed through the D-hole.

Inductance Increase & Power Flow

- A typical stripline target starts at 3.5 nH and grows from there. For typical pulse shapes current loss is not a problem and is easily compensated for (if it occurs at all).
- In some cases, the pulse shape and temporal evolution of the stripline tax the Z generator.
- Convolute loss dominated modeling had progressed substantially in the last two years, and **loss model predictions for high inductance loads are performing well**.
- Shown is a particularly high inductance, high pressure platform under development that can reach >8 Mbar in isentropic compression for high Z materials (ie Pt, W, Ta, Au). **The convolute loss model has been demonstrated to be predictive for this platform**.



Conclusion

- The unique experimental constraints of Z mean it is not a user facility, rather there is a true partnership between external collaborators and staff.
- A range of standard material science platforms exist.
- Sandia PIs and shot designers will recommend an experimental configuration to meet your needs, but there is room for modification.
- Every Z shot is custom.
- **It is imperative that you connect with a Z PI if you wish to submit a proposal. At the minimum, we can help determine if what you want is possible on present Z.**
- We are always open to platform or diagnostic development under ZFS proposals. Those collaborations have been productive in the past.