



1 Tesla Operation of the HSX Stellarator



Simon Anderson, A. Almagri, D.T. Anderson, A. Briesemeister, J. Canik, C. Deng¹, W.A. Guttenfelder, C. Lechte, K.M. Likin, J. Lore, H.J. Lu, S. Oh, J.W. Radder, J. Schmitt, J.N. Talmadge, K. Zhai
HSX Plasma Laboratory, University of Wisconsin, Madison, WI, USA; ¹Electrical Engineering Department, UCLA

1. Why 1 Tesla HSX Operation ?

Neoclassical and anomalous transport

The anomalous electron thermal conductivity in W7-AS has been observed to scale as $1/B$, so doubling the field should significantly reduce the anomalous contribution relative to neoclassical (superbanana transport is independent of the field). Scaling in anomalous-dominated stellarators sees increased energy confinement with both density and B .

Power scaling

Modeling suggests that anomalous transport may overwhelm 0.5 Tesla differences in neoclassical transport (although some differences have been seen [Canik – this session]). Operating at higher density and higher power should decrease the anomalous transport and increase the neoclassical contribution, especially in the broken-symmetry configurations.

Superthermal tail reduction

Operation at $B=1.0$ T will permit fundamental O-mode heating. This will increase the cut-off density from 5×10^{12} to 1×10^{13} cm^{-3} and reduce the energetic electron tail population which complicates interpretation of many measurements [Abdou – this session].

2. 1.0 Tesla HSX Operation

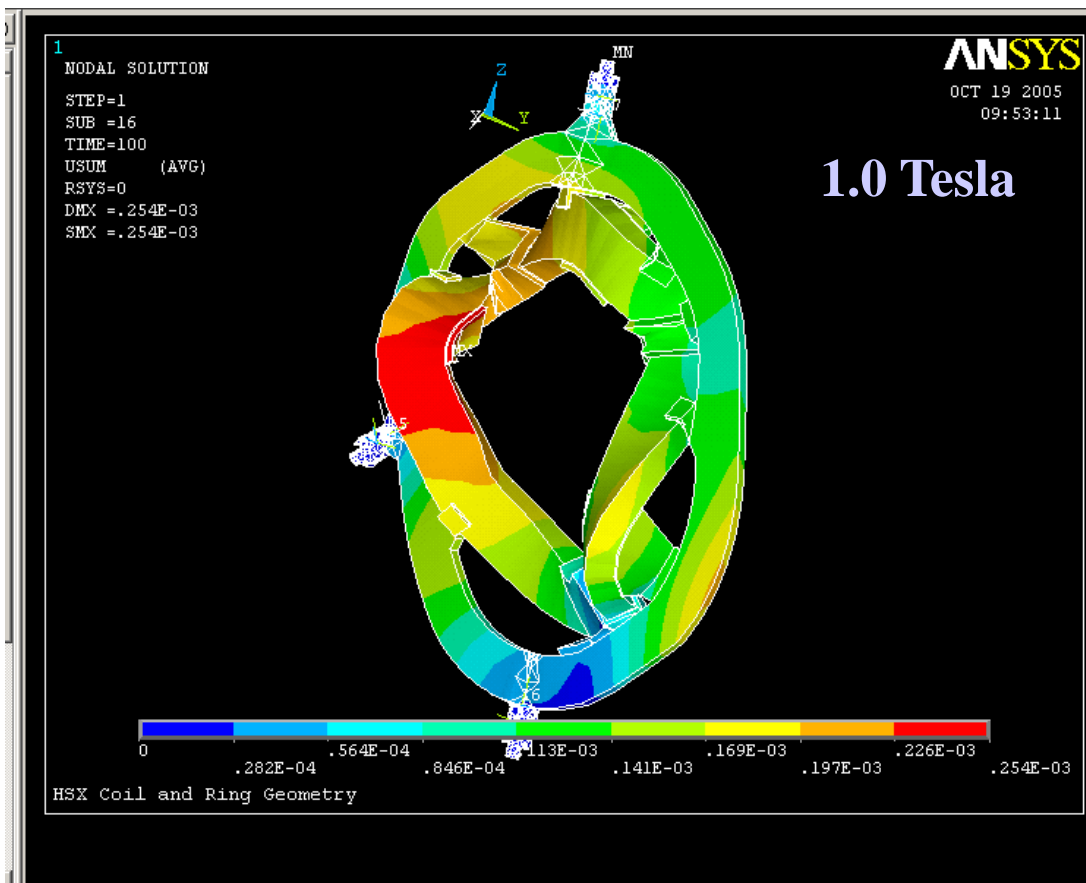
1.0 Tesla Machine requirements

- 18 Motor Generators are needed, as compared to currently 10 being used for 0.5 Tesla operation.
- 2 Auxiliary Coil Motor Generators are required for HSX configuration flexibility at 1.0 Tesla.
- Coil currents increase from 5.5 kA at 0.5 Tesla to 11 kA at 1.0 Tesla.
- Fast turn-off of the magnet coil currents limit the I^2t to equivalent 0.5T longer-pulse operation values ($\sim 5 \times 10^7 \text{ A}^2\text{s}$) – lowers heat loads and permits faster machine cycling.

ANSYS modeling

- ANSYS provides forces, coil and support stresses, and displacements.
- ANSYS provides a guide to position displacement sensors on coils and supports.
- Measured displacements at different magnetic fields provide a confidence benchmark for planned 1.0 Tesla operation.
- 1.0 Tesla QHS operation appears to have stresses and coil motions well within design guidelines and material yields for all coils and supports. Coil stresses are all under 20 MPa, while support stresses are all under 250 MPa.
- Highest loads and stresses are at the coil-to-ring attachment points and the ring support points.
- Continued model refinement is underway to improve support structure representation

Coil 5 ANSYS analysis - Displacement



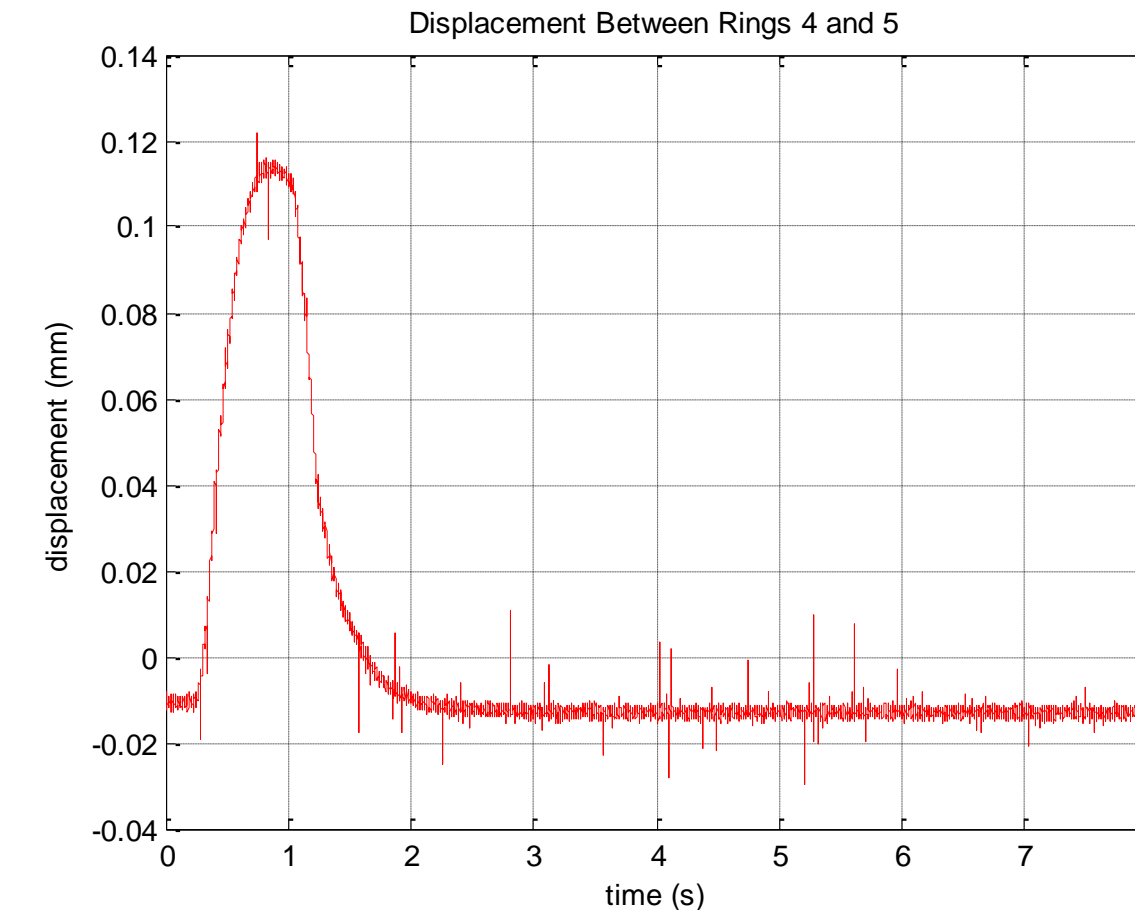
3. Magnet Coil Diagnostics

3.1 HSX Coils and MG set Diagnostics

- Coil voltages are monitored for each magnet shot.
- Coil temperatures are monitored on each side of all coil feeds for each magnet shot.
- Strain gauges are currently located at 7 locations, and are planned for multiple locations on each coil of one full field period, and selective coil locations around the device in other field periods (128 total).
 - These provide sensitive measurements of coil-to-ring, and ring-to-support, displacements (micron sensitivity)
 - Displacement signals are taken for each magnet shot.
 - ANSYS comparison for various displacements and fields/currents can be compared.
- Main and auxiliary coil currents and voltages are routinely monitored.
- Currents, armature-winding voltages and field-winding voltages are monitored for each Motor Generator.
- Each Motor Generator flywheel (2-ton) speed is redundantly monitored with optical and mechanical tachometers – all motors have been spun up to full speed for 1.0 Tesla operation, and vibration tested.

3.2 ANSYS Comparison to 0.5T HSX Operation

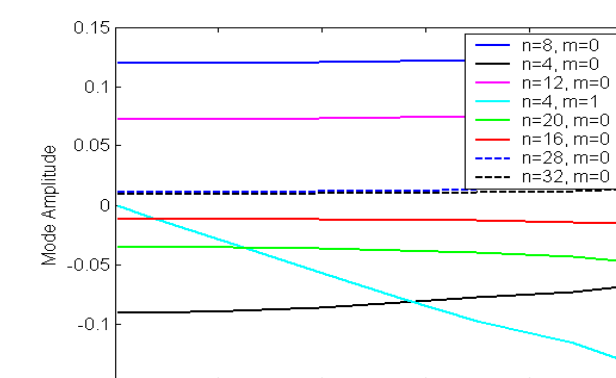
Measured Coil 4-5 motion during 0.5T QHS operation



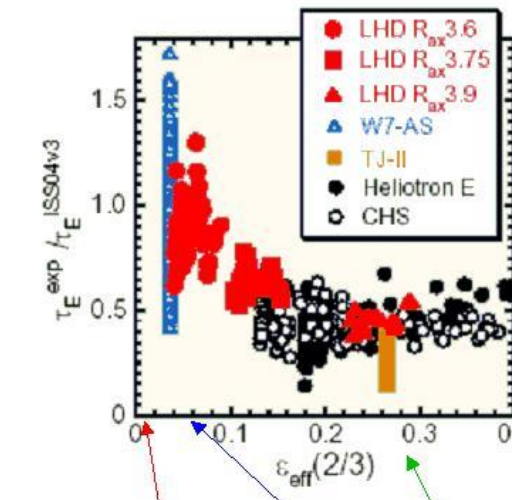
- Deflection Ring 1
Measured: 0.065mm
ANSYS: 0.094mm
- Deflection Between Rings 4&5
Measured: 0.127mm
ANSYS: 0.147mm
- Deflection on Coil 1 joint bolt
Measured: 0.010mm
ANSYS: 0.012mm

4. No Coil 3 Mode of Operation

No Coil 3 would allow for high ripple magnetics while maintaining a centered magnetic configuration – compatible with current diagnostic implementations

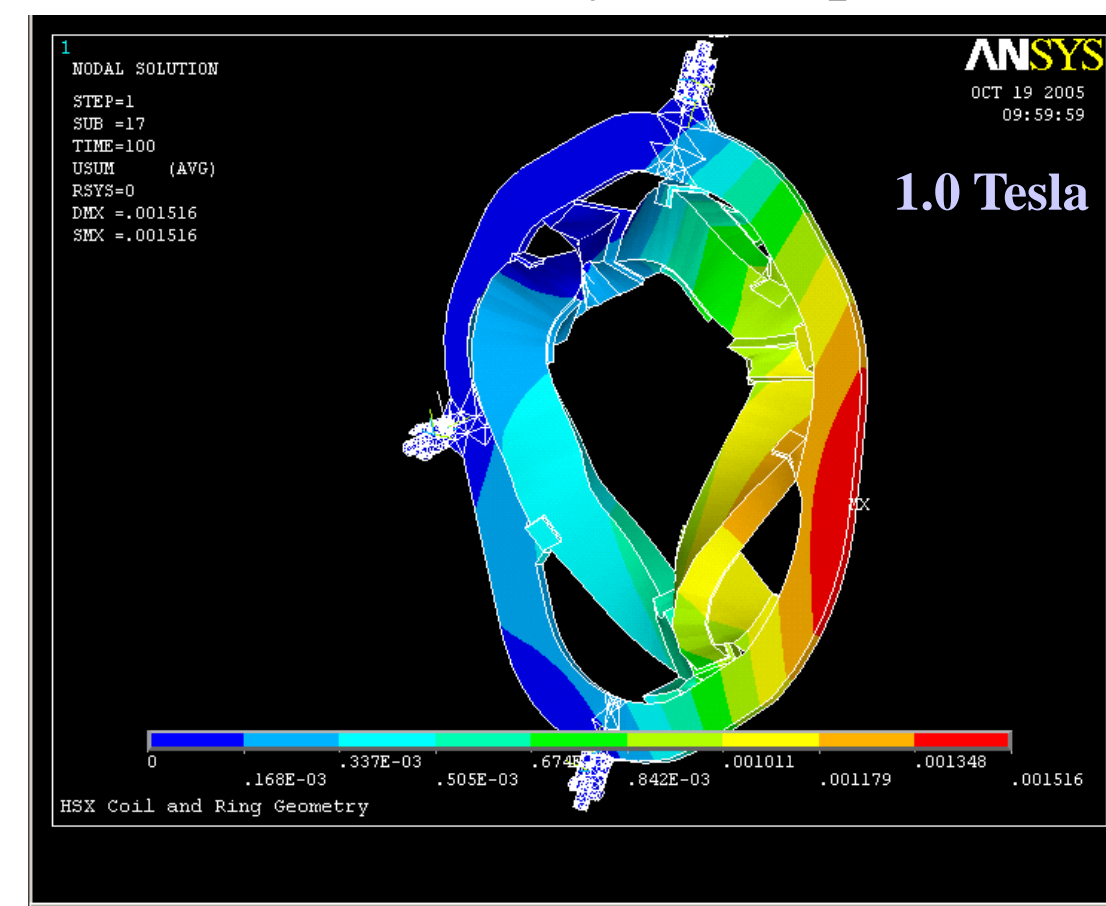


Magnetic field spectrum for No Coil 3.



Normalized Energy confinement versus effective ripple.

Coil 5 ANSYS analysis - Displacement



Forces and stresses at 1.0 Tesla on the coil supports (NOT the coils) are above material yields for full Coil 3 removal from the HSX coil set. Additional structural evaluation is underway.

5. Plasma Diagnostics and Heating

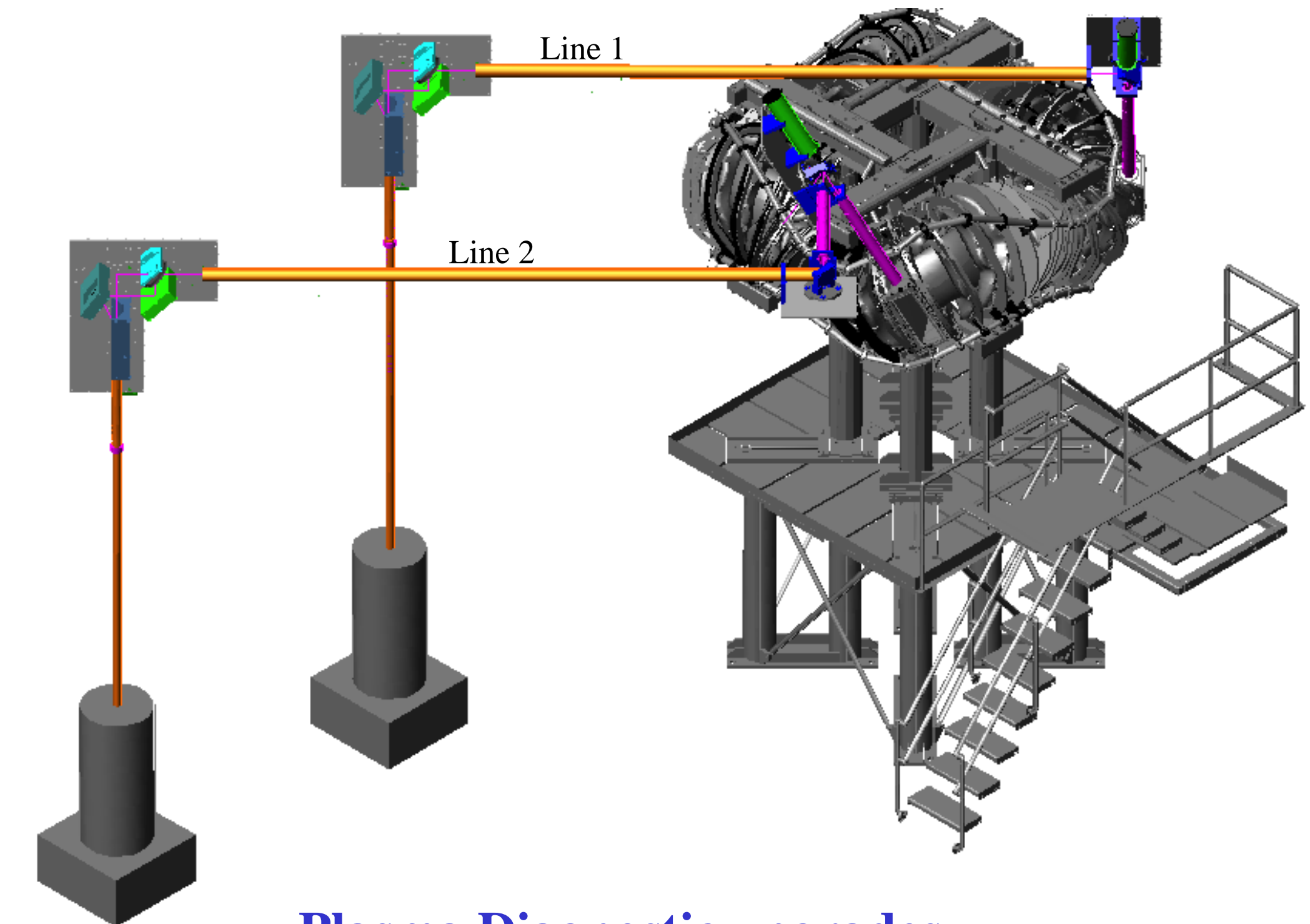
ECH Heating upgrades [Radder – this session]

Phase 1: Line 1 Upgrade

- Remove 50 kW over-moded waveguide
- Install Line 1, 200 kW quasioptical waveguide

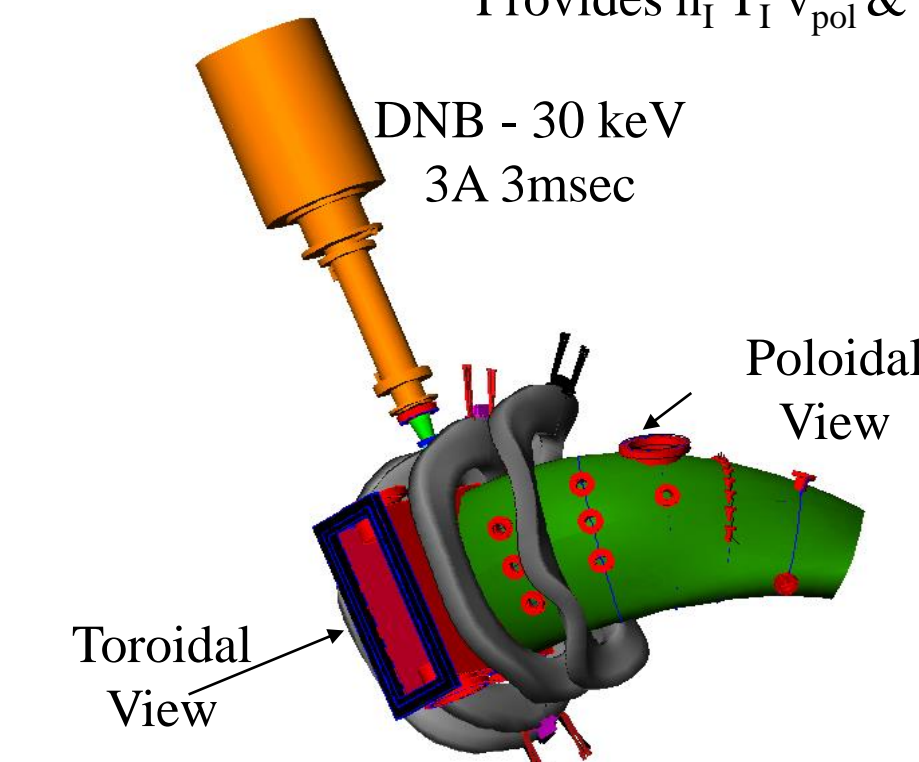
Phase 2: Line 2 Installation

- Install 28 GHz, 200 kW Varian gyrotron
- Install Line 2, 200 kW quasioptical waveguide



Plasma Diagnostic upgrades

CHERS - [Zhai – this session]
Provides n_i , T_i , v_{pol} & v_{tor}



E_r - Using the radial force balance equation, the radial electric field in the plasma can be determined from these measured quantities.

Reflectometry to investigate core turbulence.

- uses microwave radiation to measure the (electron) density of the plasma.
- Microwaves of a given frequency are reflected by cut-off layers, where n_e and B are known.
- Heterodyne detection allows calculation of the position of the cut-off layer to provide profile and fluctuation measurements.

ECE Radiometry for Te and power deposition determination.

- Modulation of gyrotron #2 ECRH power induces a localized temperature perturbation.
- Heat pulse analysis will use an expanded multi-channel ECE radiometer.