NCSX Diagnostics - Design and Integration Issues

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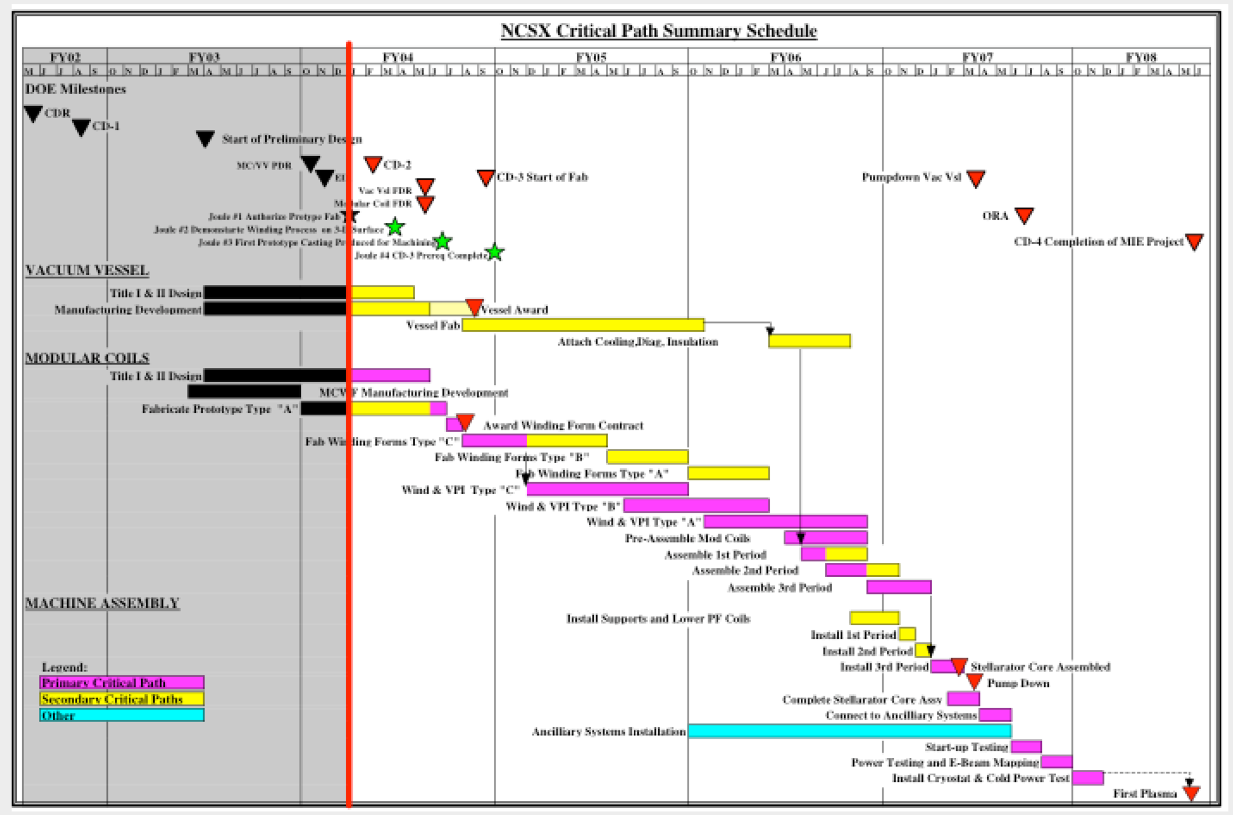
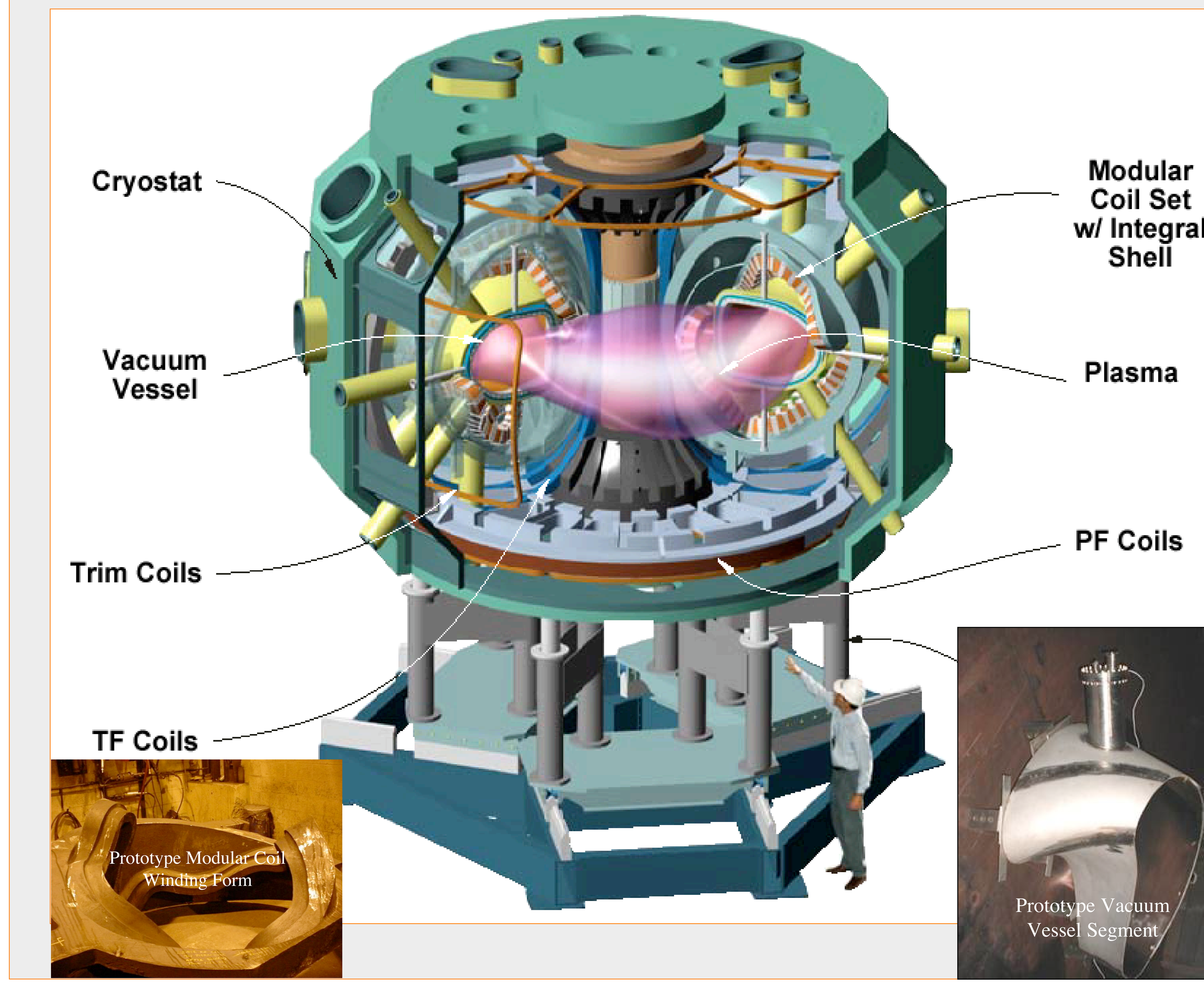
The Compact Stellarator, the NCSX Mission, and Project Status

- The mission of the National Compact Stellarator Experiment (NCSX) is to use the flexibility of 3-D shaping to combine the best features of stellarators and tokamaks. The project seeks to demonstrate high-beta, disruption-free operation by using externally generated helical fields at low aspect ratio in a quasi-axisymmetric configuration with significant bootstrap current.
- The configuration has been numerically optimized to be passively stable at $\beta = 4.1\%$ to kink, ballooning, vertical, Mercier, and NTM modes, without conducting walls or feedback systems. This configuration has 3 periods with $R/\langle a\rangle = 4.4$ and $\langle\kappa\rangle = 1.8$, and is produced by 18 modular coils (3 types), supplemented by a PF coil set and a weak TF set for flexibility. A set of external trim coils is planned to suppress m=2 islands. All coils are cooled to LN_2 temperature within a cryostat. With R = 1.4 m, B = 1.2 – 1.7 T, the design features the capability to accommodate pulse lengths up to 1.2 sec and 6 – 12 MW of auxiliary power, consisting of both tangential neutral beams (4 beamlines available from PBX), and high field launch RF heating.
- NCSX is predicted to achieve central $T_e(0)$, $T_i(0) \sim 1.8$ keV at $n_e \sim 7\times10^{19}\ m^{-3}$, corresponding to $\beta \sim 4\%$.





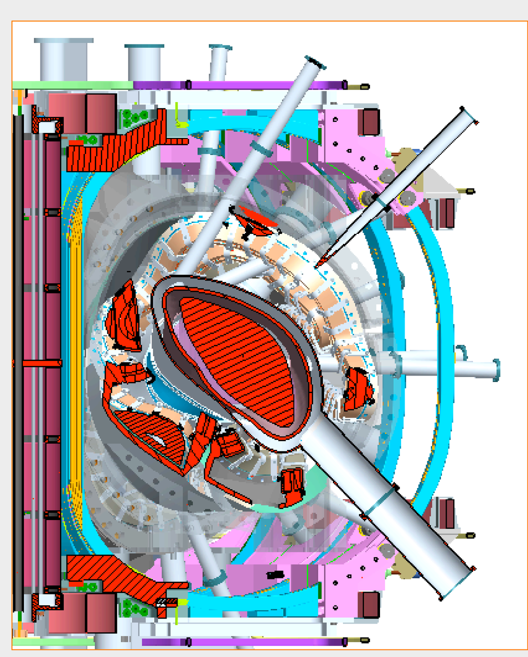
Diagnostic Implementation Phased to Support Research Plan

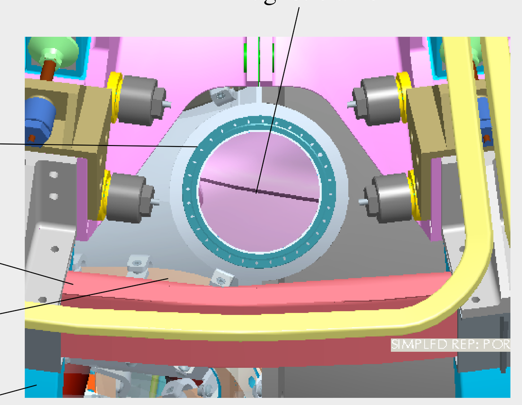
Research Phases

1. Field line mapping with room temperature coils to confirm machine assembly.
2. Initial plasma operation with $I_p > 25$ kA is followed by field mapping campaign with cryogenic coils, ending the construction project.
3. Control of plasma position and shape is a primary goal of the initial experimental phase, with 1.5 MW NBI, lasting ~ 1 year. Experiments on confinement and stability with 3-D shaping would begin in this phase.
4. The 3 MW heating phase is envisioned to last ~2 years, and will explore NCSX flexibility, plasma confinement, and stability at moderate β with NBI heating. Work on many of the diagnostics in phases 3 and 4 will have to begin before 1st plasma.
5. The goal of the high β phase (multi-year) is to extend enhanced regimes and investigate high β stability and full divertor operation.
6. Upgrades for this phase should permit equilibration of the current profile to the bootstrap current and documentation of high-β, disruption-free, long pulse operation.

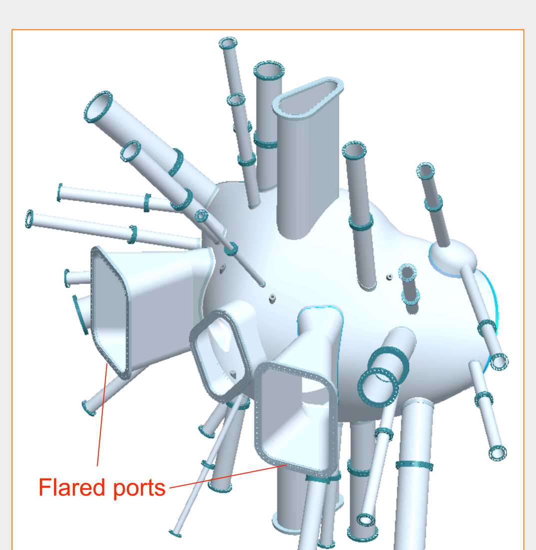
DIAGNOSTIC	DESCRIPTION	4	5	6	7	8	9	10	11	12
diagnostic integration						Project				
1. Field Line Mapping to Check Machine Assembly (B=0.5 T, room temperature)										
e-beam mapping	e-gun on probe, fluor. wire array									
ex-vessel magnetics	200 ext. sensors & few integ.									
2. Initial Plasma Operation and Cold Field Line Mapping (B=0.5 T, cryogenics)										
visible cameras	1 fast cam.+shield on beam port									
3. 1.5 MW Initial Experiments (1.5 MW NBI, B=1.2 T, partial PFCs)										
in-vessel magnetics	100 B_c coils+100 integrators									
2 filtered cameras	2 add'l cam in reent., shut. assy									
core Thomson scattering	3 spatial channels, 100 Hz									
core FIR interf./ polarim.	2 chords, λ , geometry TBD									
x-ray crystal spectrometer	imaging sys. with 2-D detector									
compact SXR arrays	8 arrays of 20 channels									
wide angle bolometer	4 channels in wide angle view									
visible spectrometer	multichan., survey instrument									
abs. UV spectroscopy	vac. UV survey instrument									
compact IR camera	no periscope, standard speed									
plate mount Langmuir probes	array of fixed probes									
fast neutral pressure gauges	midplane and banana tips									
moveable Langmuir probe	moveable between shots									
visible filterscopes	several sightlines									
4. 3 MW Heating (3 MW NBI, full PFCs, B=2.0 T, 350 C bake)		4	5	6	7	8	9	10	11	12
additional magnetics	add 50 varied sensors & integ.									
Thomson profile system	60 spatial channels, 100 Hz									
FIR interf./ polarim. profile	full array of detectors									
filtered 1D CCD camera	single view									
core foil bolometer array	12 add'l channels (16 total)									
diagnostic neutral beam	50 kV, 6 amps neutrals, 6 cm									
MSE polarimeter	uses DNB, midplane view									
toroidal CHERS	uses DNB, midplane view									
enhanced x-ray tomography	additional 8 compact SXR arrays									
poloidal CHERS	uses DNB, vertical view									
fast tang. x-ray camera	uses unused beam port									
fast ion loss probe	geometry TBD									
neutral particle analyser	legacy analyzer (PLT or NSTX)									
epithermal neutron detector										
high frequency Mirnov coils	12 larger TFTR style coils									
5. Confinement & β push (3 MW NBI & 6 MW NBI or RF, divertor)										
divertor foil bol. arrays	2 crossed, 16 channel arrays									
divertor filtered CCD camera	view TBD									
fast IR camera	needs periscope									
fast scanning edge probe	geometry TBD									
He CHERS system	uses DNB									
divertor thermocouples	instrumented divertor tiles									
divertor UV spectroscopy	dedicated divertor view									
fluctuation diagnostic	TBD									
6. Long pulse (Existing heating & 3 MW long pulse NBI or RF)		4	5	6	7	8	9	10	11	12
divertor Thomson scattering	100 hz, 20 spatial channels									

Diagnostic Access





View down axis of port



Diagnostic Port Design

Much of the recent NCSX effort in diagnostics focused on optimization of diagnostic ports. In the present design, diagnostic extensions are generally positioned on radial planes aimed at the magnetic axis, in locations where they would clear modular coils, TF and PF coils.

Along the length of a particular extension, an intermediate vacuum seal is placed outboard of the modular coil support "shell" but inboard of the cryostat boundary. There is some flexibility in customizing the outer sections. This flexibility is facilitated by a close-fitting, conformal cryostat featuring removable panels that can be tailored to diagnostic space needs.

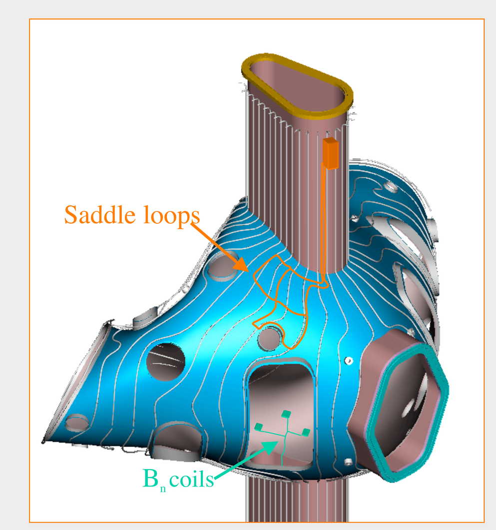
Nonetheless, the extension lengths will drive the design of many diagnostics to compact, re-entrant systems, requiring temperature regulation.

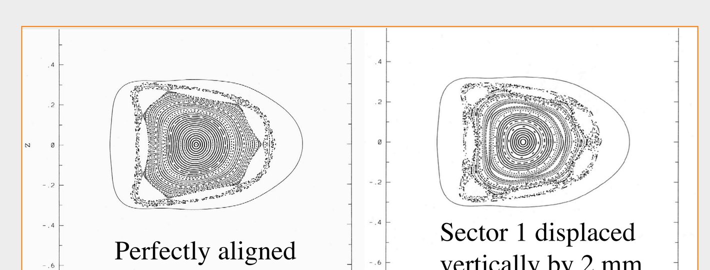
The present design has 105 ports, including 4 for neutral beam injectors. Each of the three neutral beam ports and the six flared ports are quite large, and can easily accommodate several diagnostics. Approximately 75% of these ports are allocated to the diagnostics in the table at the upper left. Additional ports can accommodate auxiliary systems (fueling, wall conditioning, etc.) and future diagnostic needs. Preliminary port allocations, this poster and talks from the satellite meeting can be found at:

http://ncsx.pppl.gov//Scientificconf/ScientificConf_2004.html

Diagnostic Challenges Specific Systems

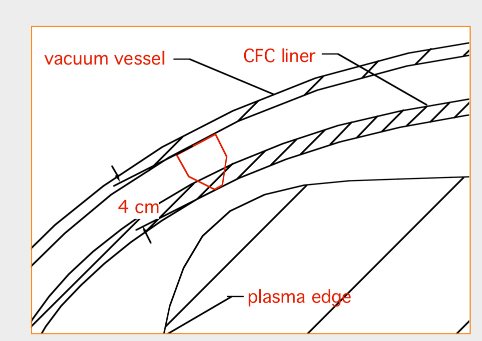
Magnetics -- There is little experience controlling the flux evolution of a plasma in 3-D from discharge initiation to the high-beta phase. As part of the ongoing design, detailed modeling is being developed (E. Lazarus and N. Pomphrey) to optimize the number, type, and placement of the sensors needed for 3-D equilibrium reconstruction and plasma control. An extensive array of external saddle loops in planned, in addition to an internal array of small B-probes and a set of co-wound flux loops on all coils. The modeling is the initial phase of a larger project to build a 3-D equilibrium reconstruction code, which will a valuable tool for interpretation of diagnostics data.

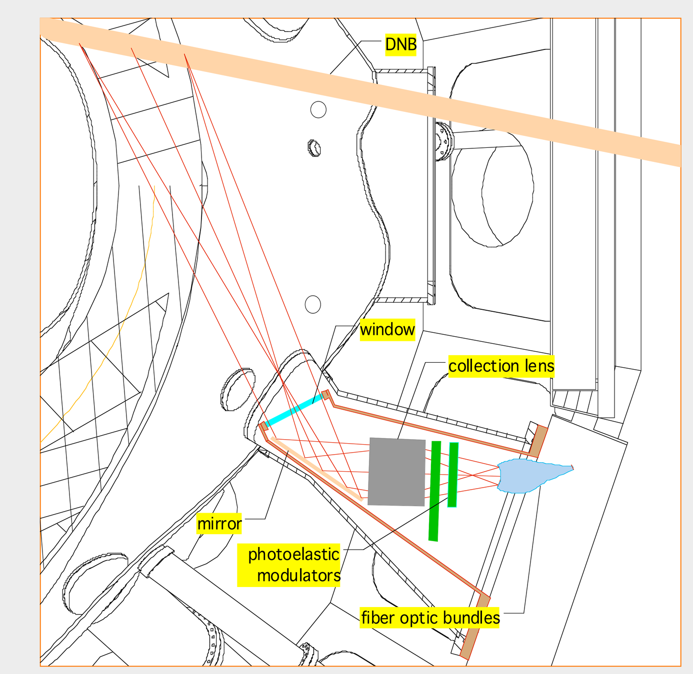




Vacuum Field Mapping -- In order to verify the symmetry of the assembled machine, we plan to use the traditional mapping technique involving an electron beam that lights up a movable fluorescent rod as the beam makes many traverses along a field line. Light is detected by a CCD camera located at a suitable viewing window. The PIES code has been used to simulate the effect of various misalignments. One case is shown at the left. Here a 2 mm displacement produces 2/5 islands with a width of ~ 2 cm. There is not enough information with this technique to unequivocally identify sources of misalignment - will have to rely on careful metrology. This study shows that beam detection at the 'bullet' cross-section will produce the best-resolved islands.

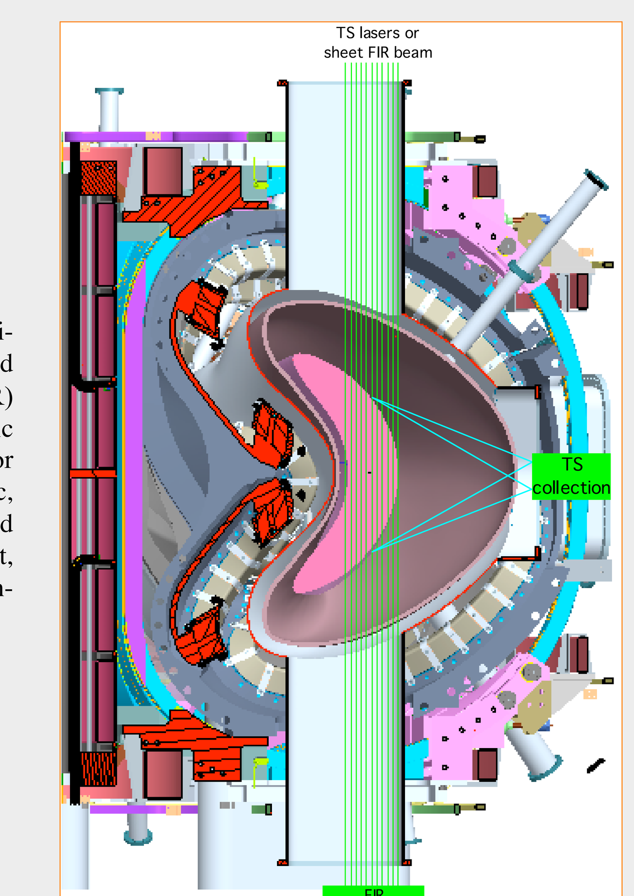
X-ray tomography -- In order to achieve adequate x-ray tomography coverage on NCSX, it will be necessary to install compact arrays between the first wall and the vacuum vessel, as shown at left. Currently, there is not a design available that is compact enough to fit within the 40 mm space constraint. In the current plan, we integrate compact arrays into one of the spacer flanges (shown at right) which join the 3 vessel segments together at the bullet cross-sections.





Active Spectroscopy -- The NCSX heating beams inject nearly parallel to flux surfaces. Because of the large beam cross-section, this means that viewing the intersection of a heating beam with the plasma region from any position results in sightlines that cross many flux surfaces resulting in poor spatial resolution. A DNB will be necessary for CHERS and MSE measurements. Viewing the DNB from the flared port as shown at the left provides optimum spatial resolution, and sufficient Doppler shift for the MSE measurements.

FIR Interferometer/Polarimeter and Thomson Scattering -- A multi-channel FIR system will use a sheet beam through the radially-elongated vertical ports, as shown at the right, to measure $n_e(R)$, $j(R)$, and $B_p(R)$ fluctuations. Because of the moderate density and relatively low magnetic field on NCSX, it will difficult to use conventional ECE techniques for measuring $T_e(R,t)$. Thus Thomson scattering will be a key diagnostic, providing time-resolved profiles for T_e and n_e. High spatial resolution would be very useful, for example, to characterize island structures. At this point, several strategies are being considered, all of which will require high-throughput collection optics, such as those shown at right.



Participation in NCSX Diagnostics

Diagnostics are entry points for establishing collaborative participation in NCSX, as on many other devices. Timeline for participation:

NCSX Research Forum	Spring 2005
1st Solicitation	FY06
Initial Funding	FY06, FY07
2nd Solicitation	FY07

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