Development of Operational Scenarios and Edge Diagnostics for the NSTX Liquid Lithium Divertor

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and the NSTX Research Team

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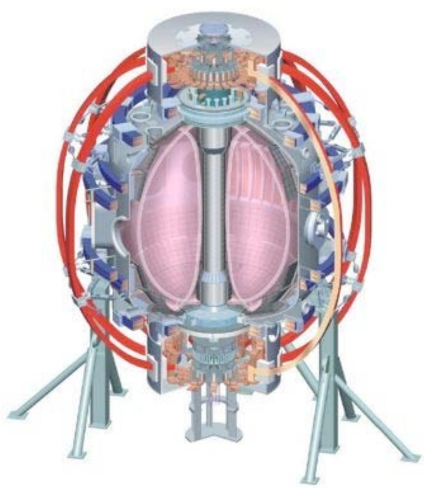

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Abstract

During the 2010 run campaign, NSTX will continue to investigate the effects of lithium plasma facing components utilizing a Liquid Lithium Divertor (LLD), to be installed this outage. In order to balance the pumping capabilities of the LLD (located on the outboard divertor) with the performance benefits of high-δ discharges (typically with the strike points on the inner divertor), a new intermediate-δ discharge was developed. The development of operational LLD-ready scenarios utilizing this shape and new strike point control algorithms will be discussed. In addition, new diagnostics will be necessary to better assess the effect of the LLD on edge plasma parameters. Several diagnostics are reviewed, including a high density Langmuir probe array for measurements of plasma density and temperature in the vicinity of the LLD.

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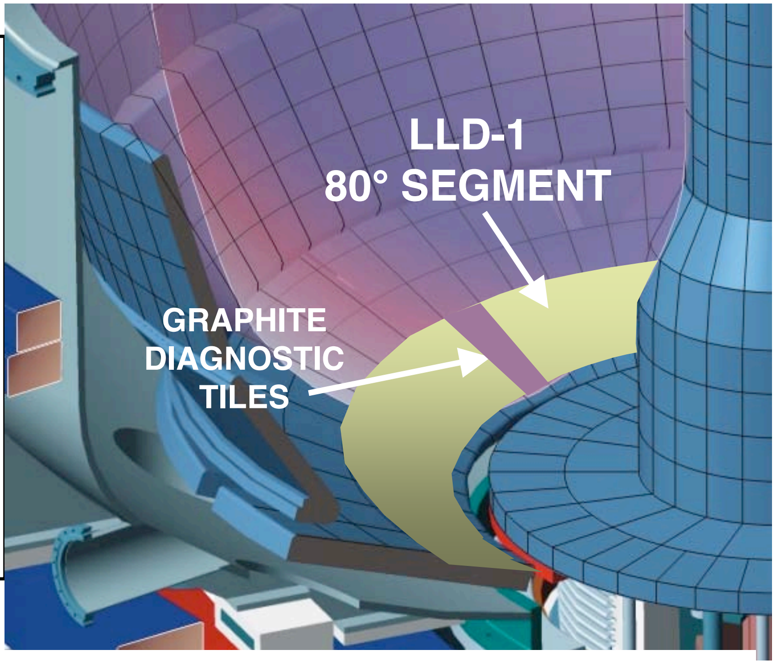
NSTX is in the process of installing a Liquid Lithium Divertor (LLD) module for FY10 operation

- Location - lower outer divertor in four 90°sections.
- Width - 20 cm starting 5 cm outboard of CHI gap.
- Shape - replaces present graphite tiles.
- Structure - 0.01cm Mo plasma-sprayed on 0.02 cm SS brazed to 1.9 cm Cu. Resistive heaters and cooling lines maintain 200-400°C.
- Li Loading - 2 lithium evaporators.

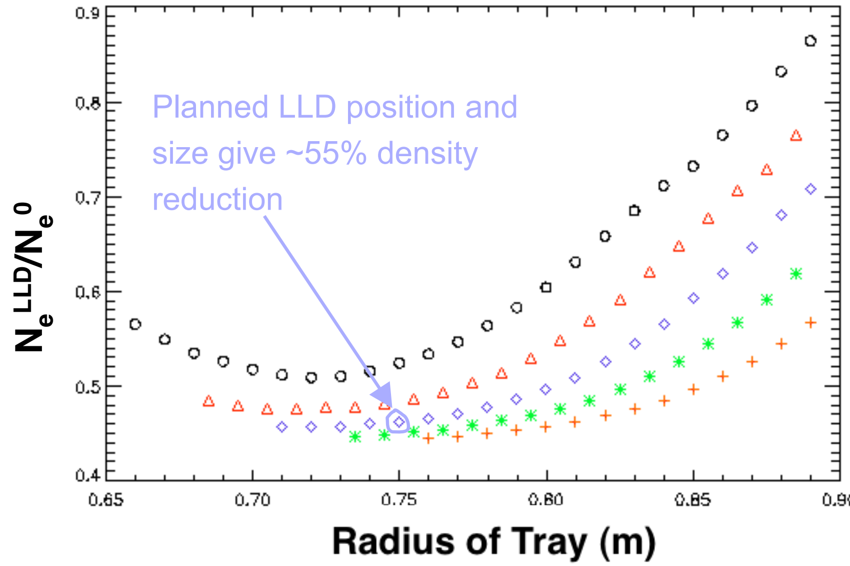


- Each toroidal section electrically grounded to vessel at one mid-segment location to control eddy currents
- Each toroidal section fastened at 4 corners to divertor copper baseplate with fasteners providing structural support, electrical isolation, and accommodating thermal expansion (design adopted from JET PPPL collaboration)
- Narrow graphite tile transition regions between sections contain thermocouples, an array of Langmuir probes, and magnetic & current sensors
- Installation is in progress, and the final plates are being installed as you read this poster
- See poster PP8.044 by H. Kugel for more information

H. Kugel, PPPL

FY09 Run Goals

- For planned LLD operation, it was desired to develop a discharge that balanced the performance benefits of high-δ plasma shapes with the higher expected pumping rates of low-δ shapes



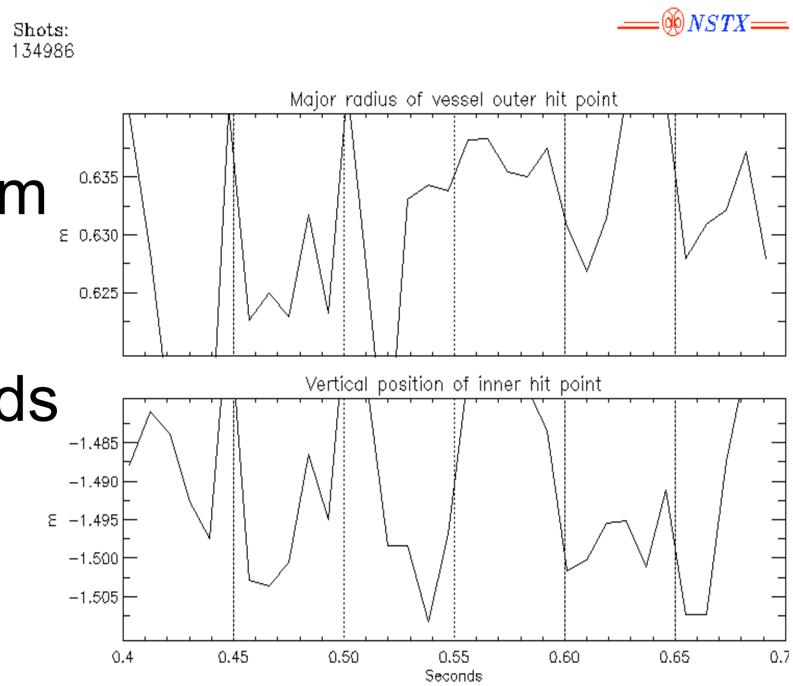
R. Maingi, ORNL

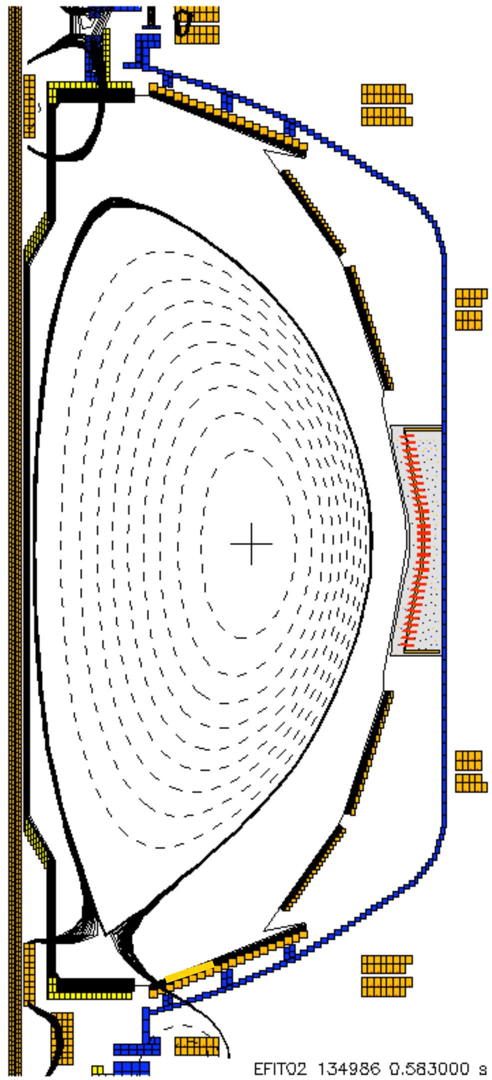
- To achieve this shape, it was necessary to control the outer strike point location to place the strike point on the bull-nose tile (R~0.63 m) between the CHI gap and the LLD
- Basic profiles (T_e, n_e, P_{rad}, equilibria) and impurity and heat flux data would be obtained for use in elucidating heat and particle deposition on the divertor in this discharge shape and to guide operation in the presence of the LLD

Discharge shape was developed and 38 plasmas were run over ~1.25 days

- Outer and inner strike point control algorithms were developed by E. Kolemen (see poster PP8.080) and utilized to produce stable discharges of the desired LLD shape

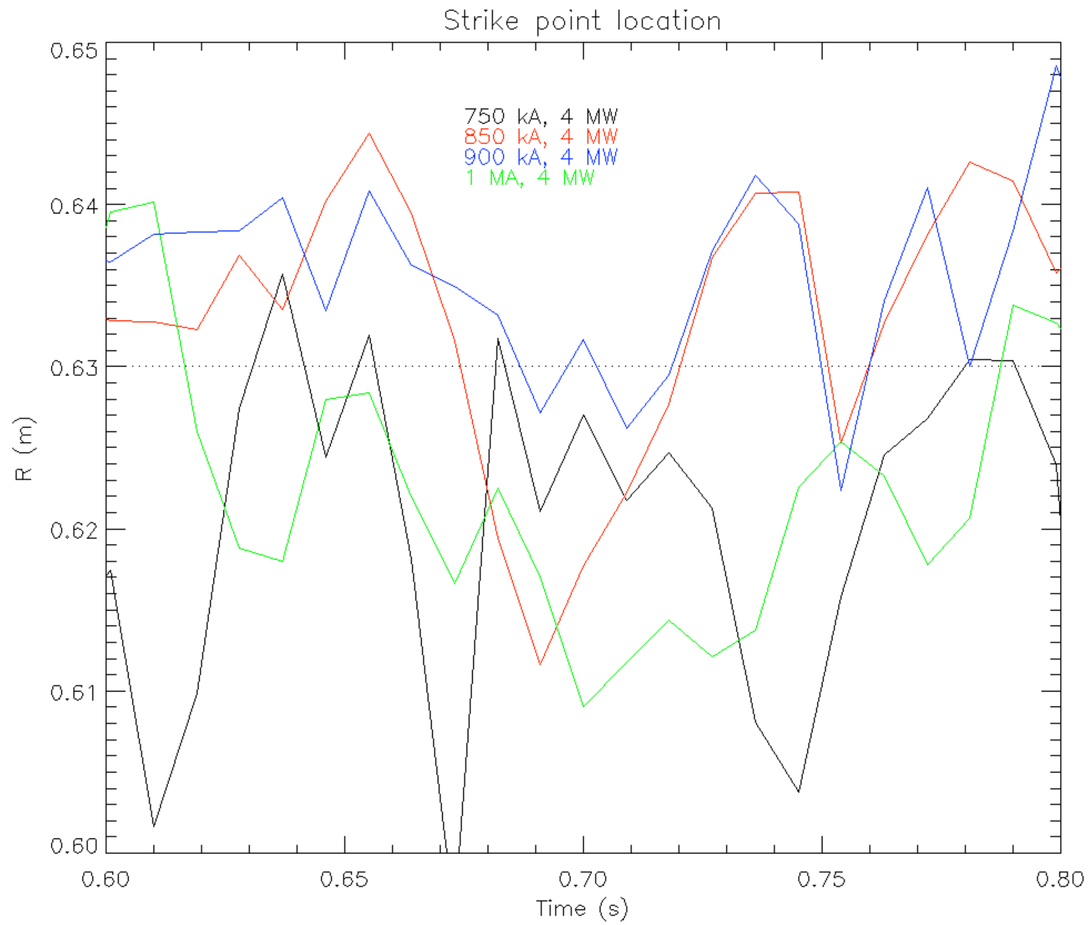
- The algorithms provided +/-1 cm control of the strike point for extended periods during shots



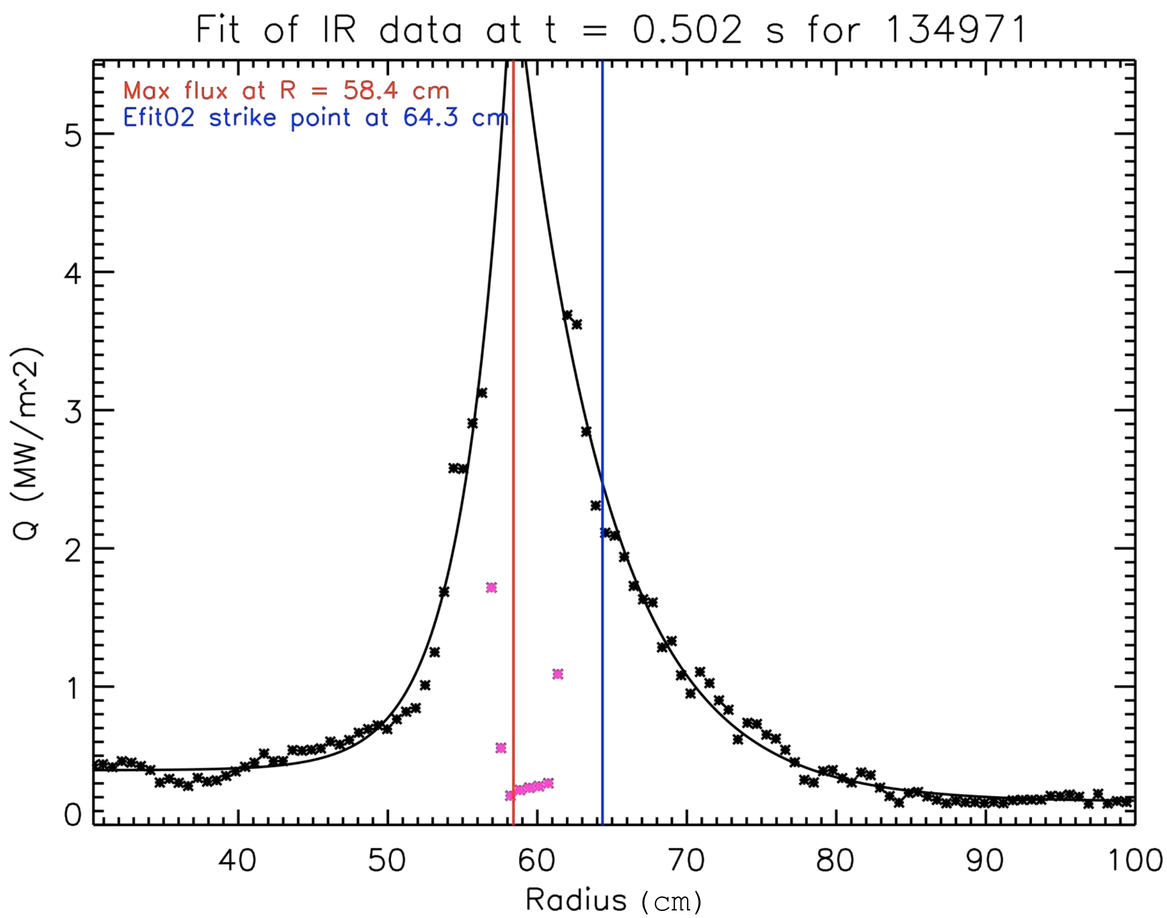


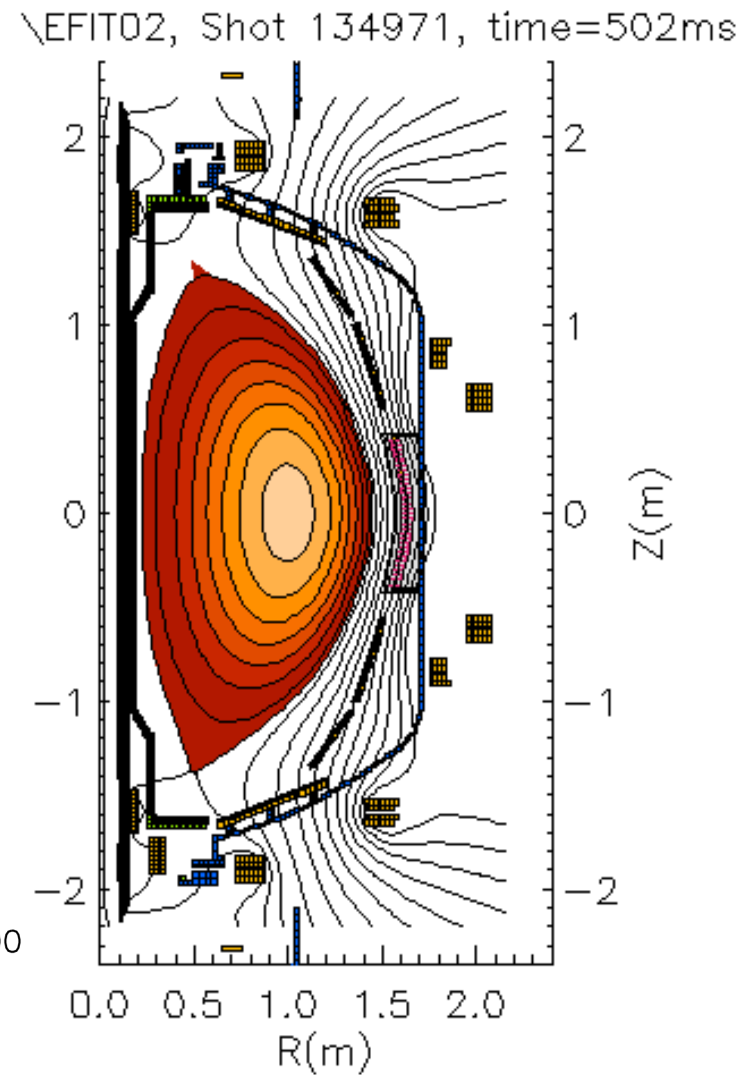
Power scan was performed to study robustness of the strike point control under varying current and input power conditions

- Shots were performed at varying plasma currents and powers
  - 750 kA – 2, 3, 4, 6 MW
  - 850 kA – 2, 3, 4, 5 MW
  - 900 kA – 4 MW
  - 1 MA – 2, 3, 4, 5 MW
- Outer strike point stayed within a ~2 cm range for several energy confinement times
- Gains on strike point control algorithms were further calibrated for use with other XPs



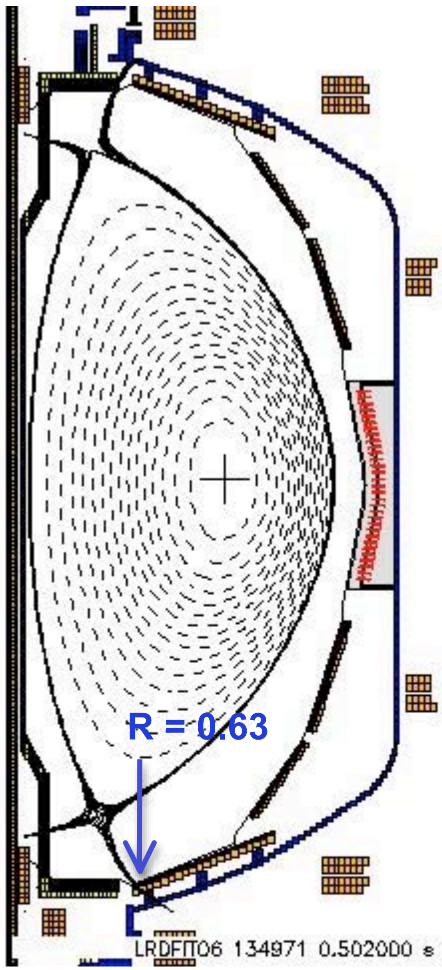
But divertor strike point did not coincide with peak heat flux from IR camera data





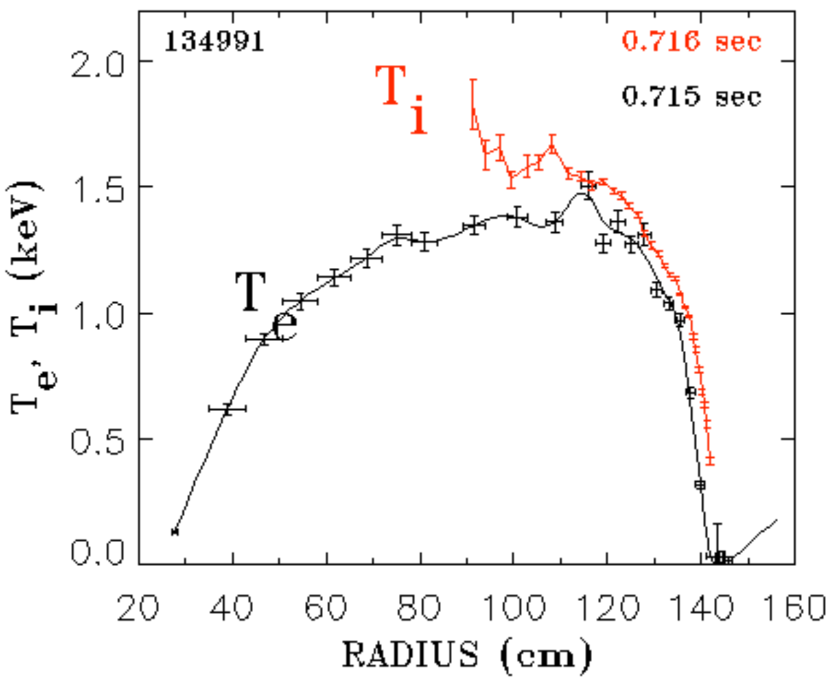
More thorough LRDFit analysis agrees with initial EFIT estimate of strike point location

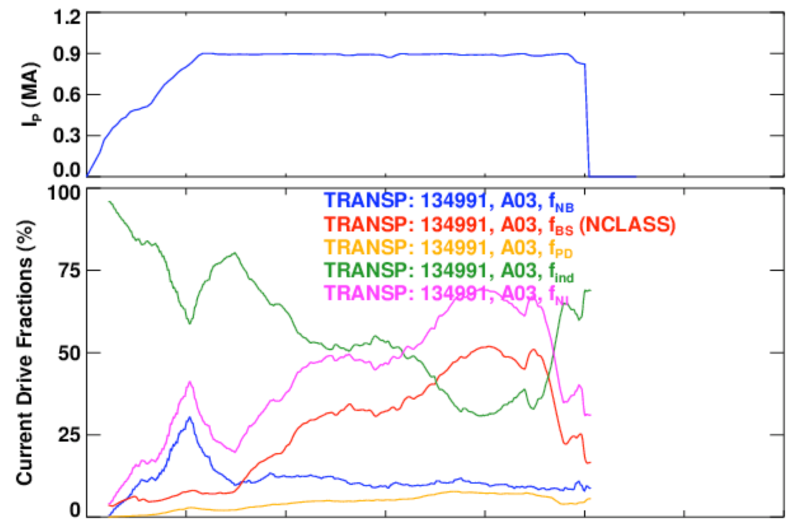
- LRDFit06 calculations show strike point at R=.631 at time of interest
  - suggests errors in magnetic reconstruction of shot or possible new physics in peak of heat flux not corresponding to strike point location
- Heat flux is well-calibrated spatially due to easily identifiable location of CHI gap in NSTX
- Investigations of magnetic signals are in process
  - strike point control algorithm matches flux at strike point and x-point, so relies heavily on magnetic interpretation
  - once discrepancy is resolved no additional changes to algorithm should be necessary



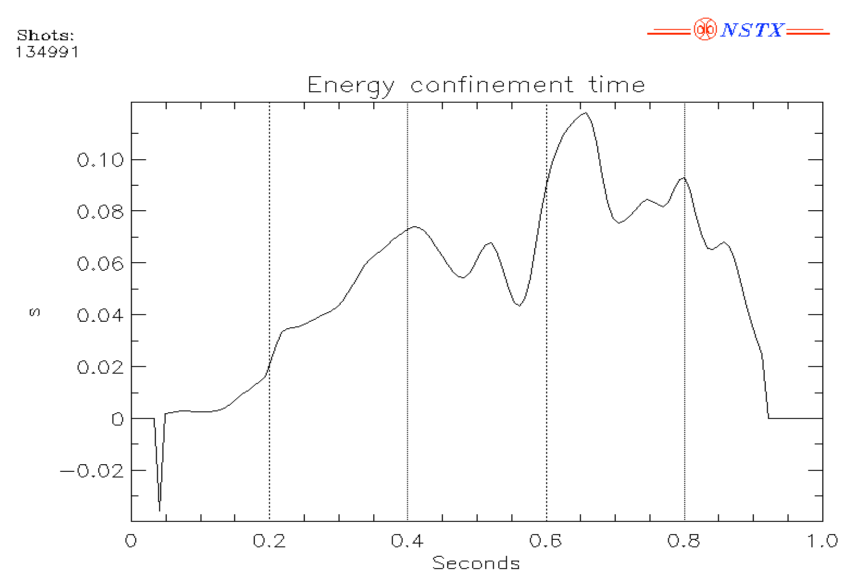
Discharges showed good performance with high levels of Li evaporation

- Using 400 mg of Li deposition, 4 MW of beam power, strike point control, and SGI fueling (see next slide), the intermediate-δ shape was optimized for LLD operation beginning in FY10
- β_N of ~6.8% (m•T/MA) achieved



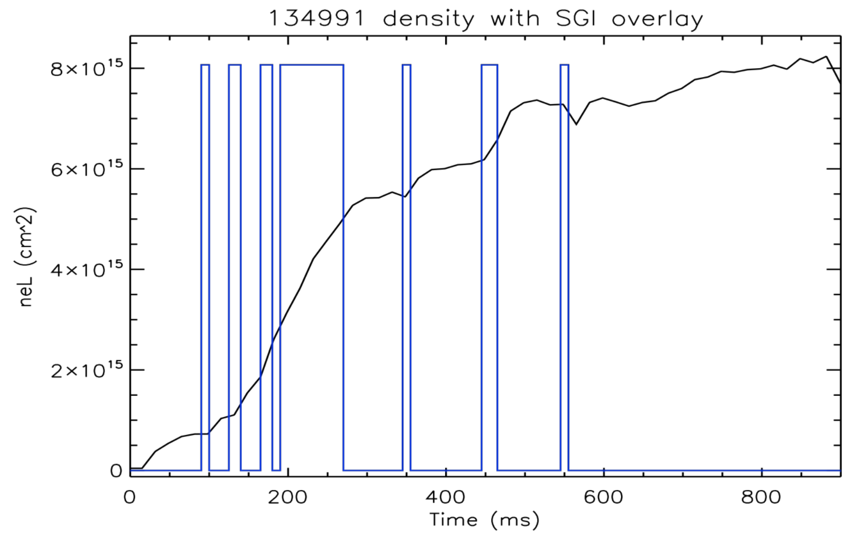


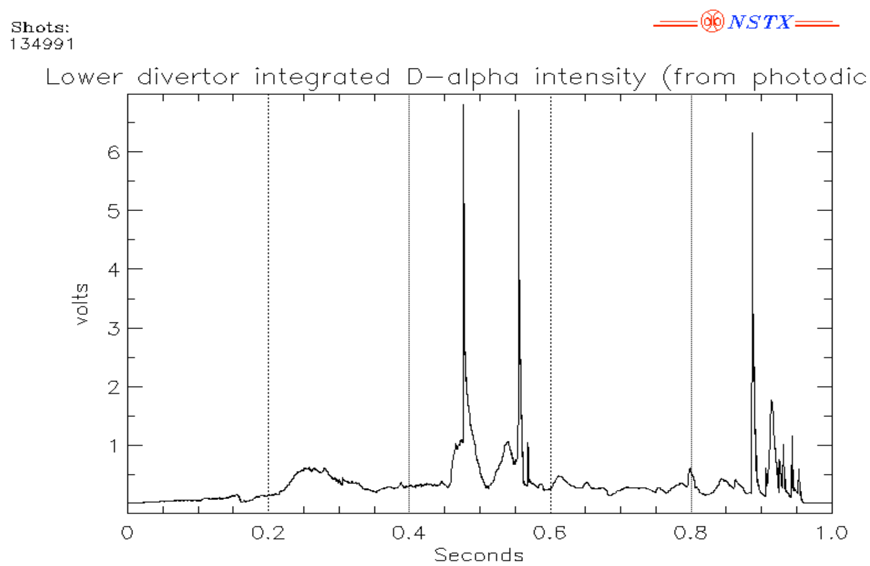
S. Gerhardt, PPPL

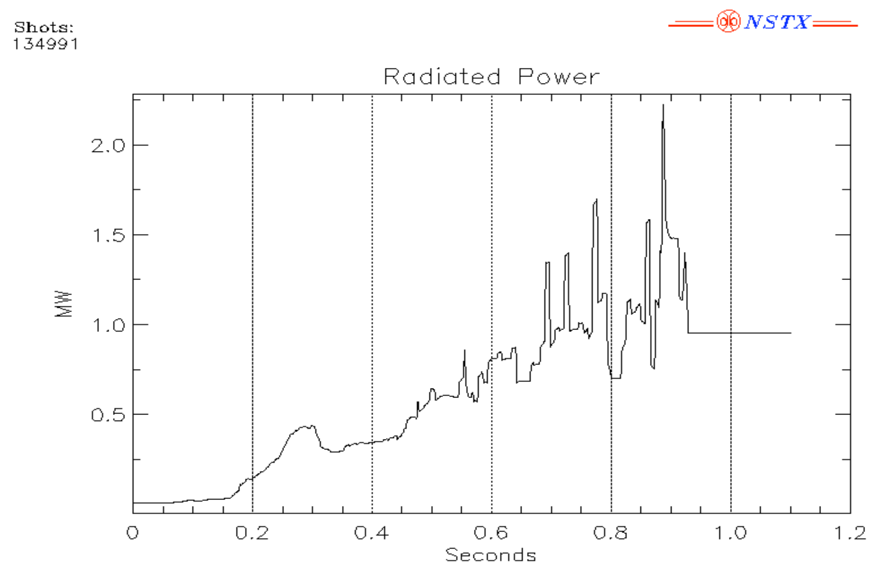


Supersonic Gas Injection (SGI) successfully used to fuel discharge

- SGI run at 5000 Torr using waveform from 133102 (V. Soukhanovskii, LLNL)
- CS gas reduced to 940 Torr L/s
- Sustained H-mode with nearly steady-state density was produced with significant Li evaporation
- Rise in radiated power still observed

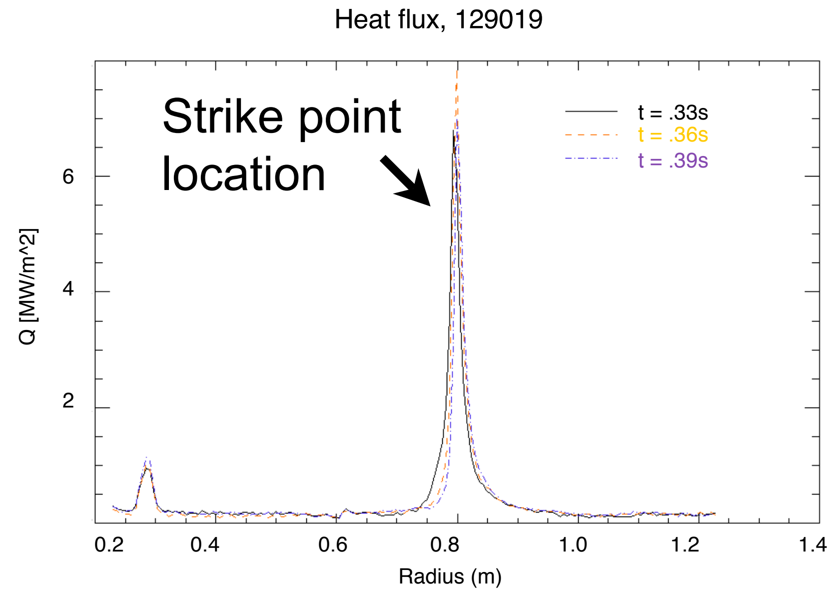


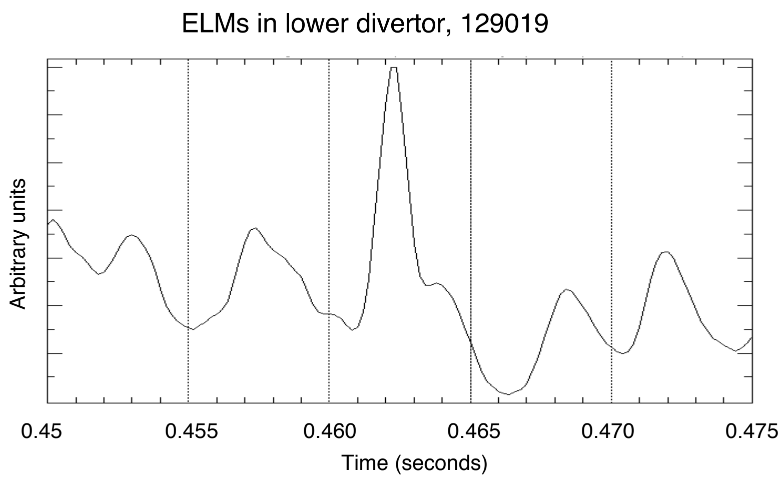




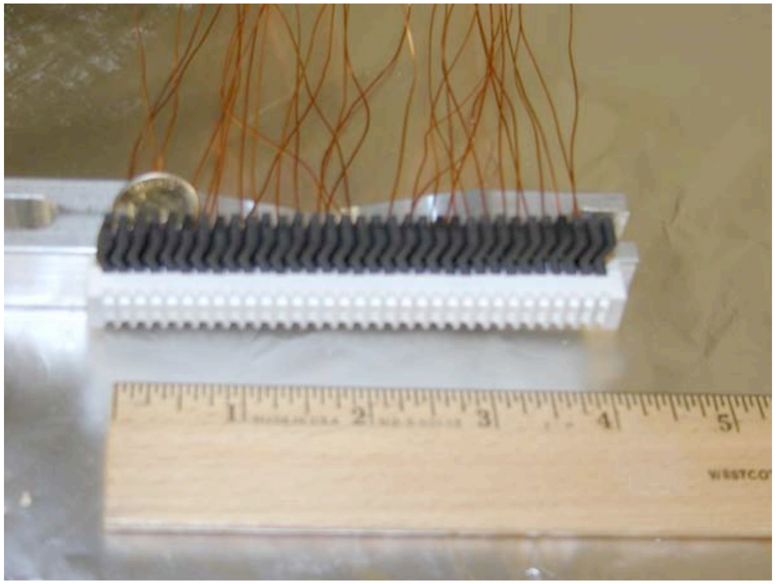
Physics requirements for the Langmuir probe array

- Limited coverage of existing edge diagnostics necessitates a new method for measuring plasma parameters (n_e, T_e, Γ) in the divertor region, especially with the LLD installation
- Heat flux profile at outer strike point has FWHM of 10 cm
  - current IR camera resolution is 16 data points over this region
  - higher spatial resolution could allow more accurate particle flux measurements
- ELMs occur on a time scale of several ms
  - temporal resolution should be sufficient to operate during transient events (single tip probes would be limited by voltage sweep rate)
  - triple probes would provide instantaneous data



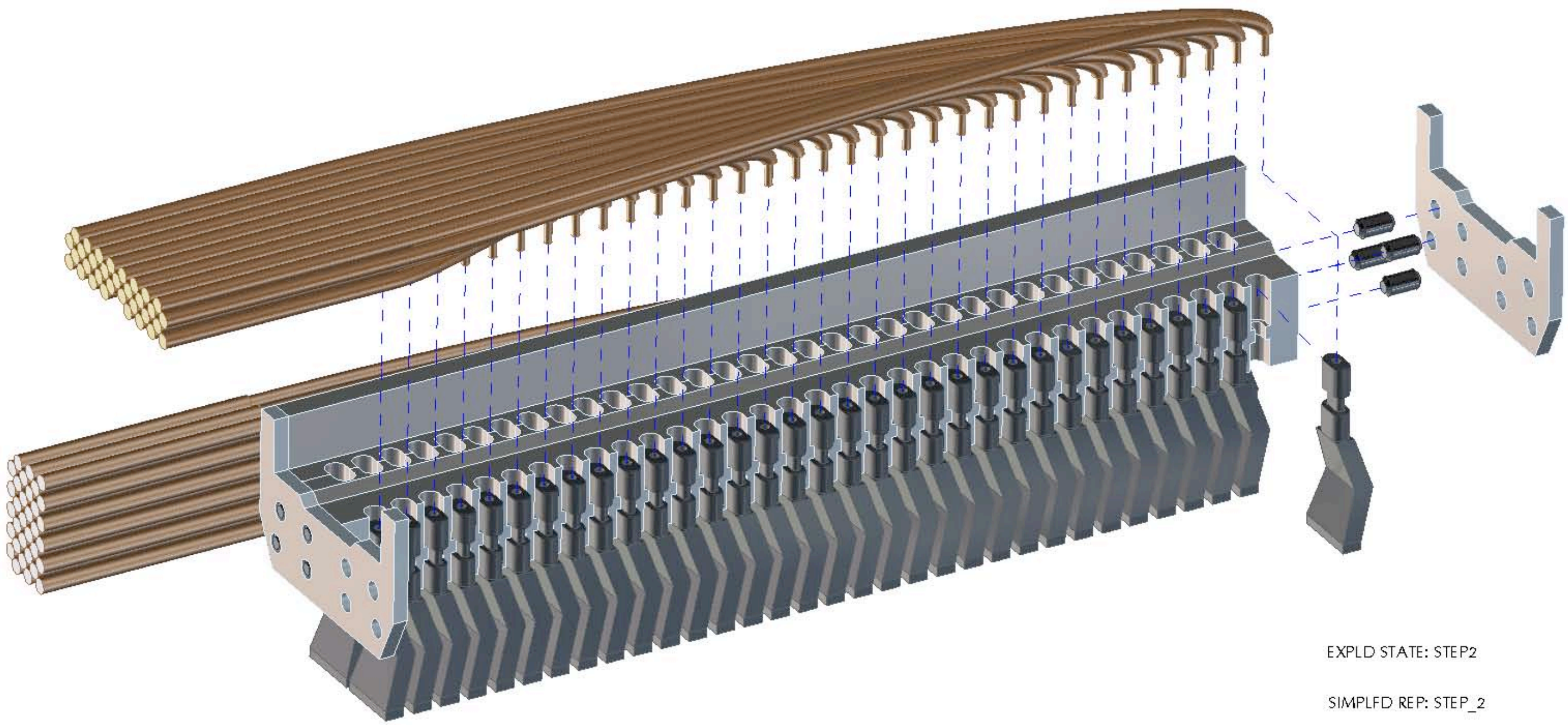


Triple Langmuir probe array will address edge diagnostic needs



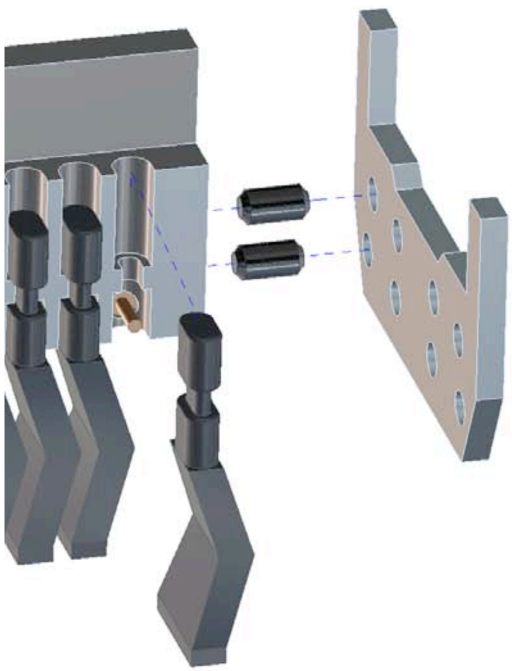
- 33 radially arrayed triple-probes will provide edge temperature and density characterization on a continuous basis
- Probes based on MAST design involving a macor cassette of closely spaced probes embedded in a carbon tile
  - tile mount with radial coverage of divertor (Bay B)
  - electronics to be provided by UIUC
- Close spacing of probes will provide better resolution in high-gradient (strike point) regions
  - each probe covers 3.5 mm radially, including spacing
  - probe heads are 2.5mm radial x 7mm toroidal rectangles

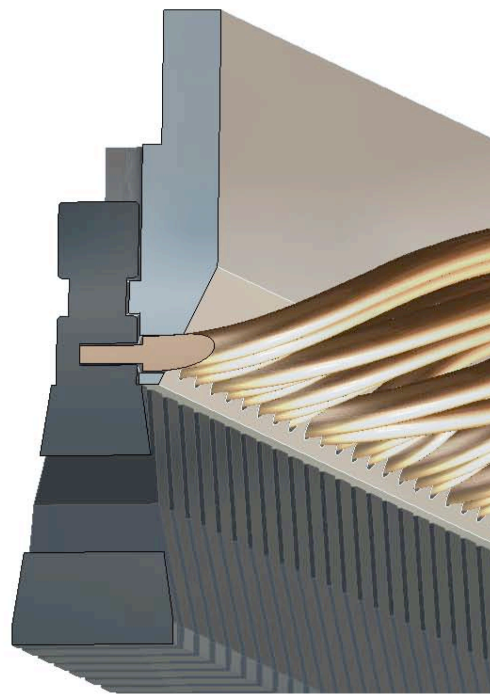
Cassette design will allow for ease of probe mounting and will include channels for wire transport



- Boron nitride cassette features interlocking segments that allow for individual probe seating and securement
  - screwless design reduces mechanical stresses on the probes
- Wiring channels allow for the wires from each group of probes to exit independently
  - wires will exit on sides of edge probes and through base of central probes

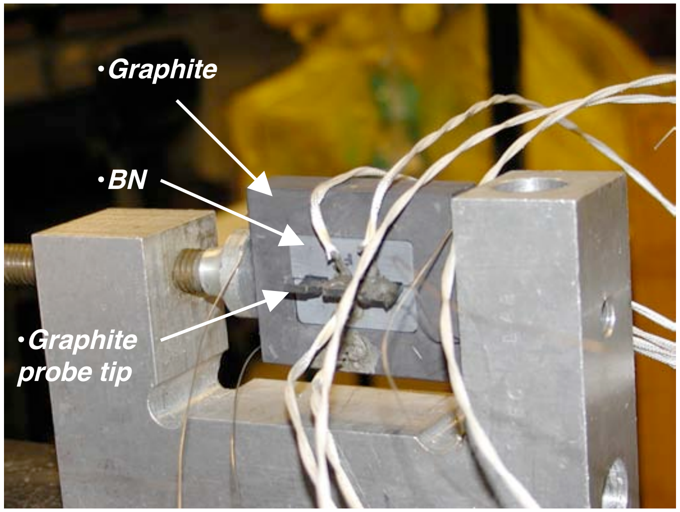
Probe design includes features to protect underlying surfaces and uses novel materials to facilitate assembly

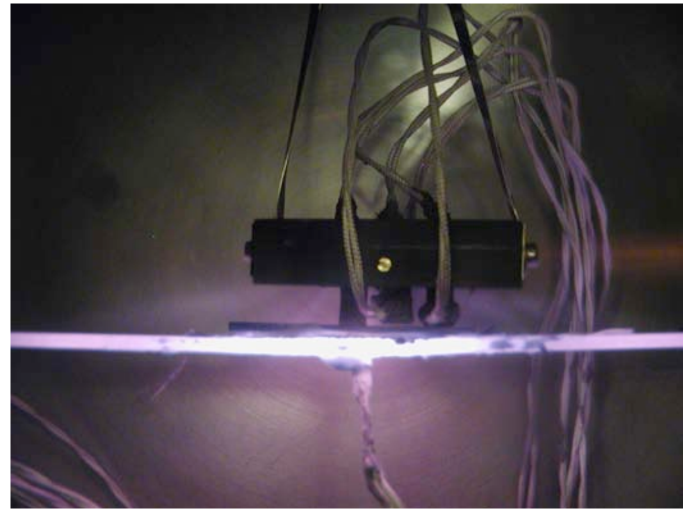


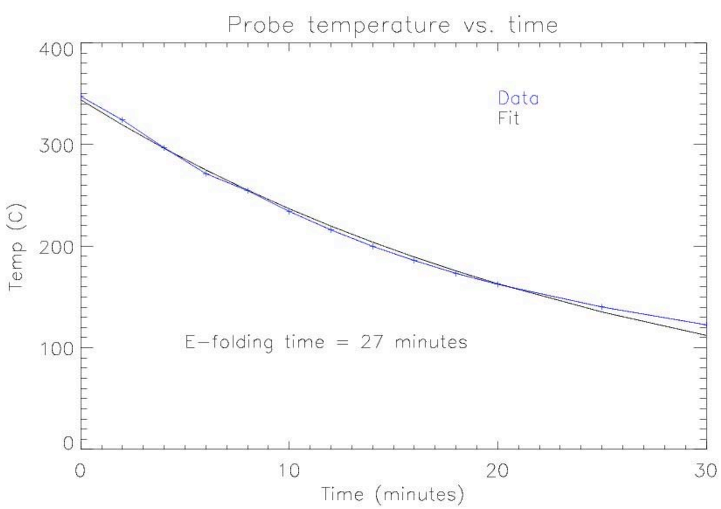


- Boron nitride offers high degree of lithium compatibility
- Probes will be shaped so as to minimize direct exposure of BN to plasma or lithium
  - probe bend prevents direct line of sight for lithium or plasma down to cassette
  - probe widening at top allows for smaller gaps and greater shielding of surfaces below
- Probe fabrication is complete and tile assembly is in process
  - material is vacuum compatible HK-6 Tokai graphite
  - wires are attached with graphite cement, obviating need for mixed materials or additional screws

Behavior of probe tip tested under heat load



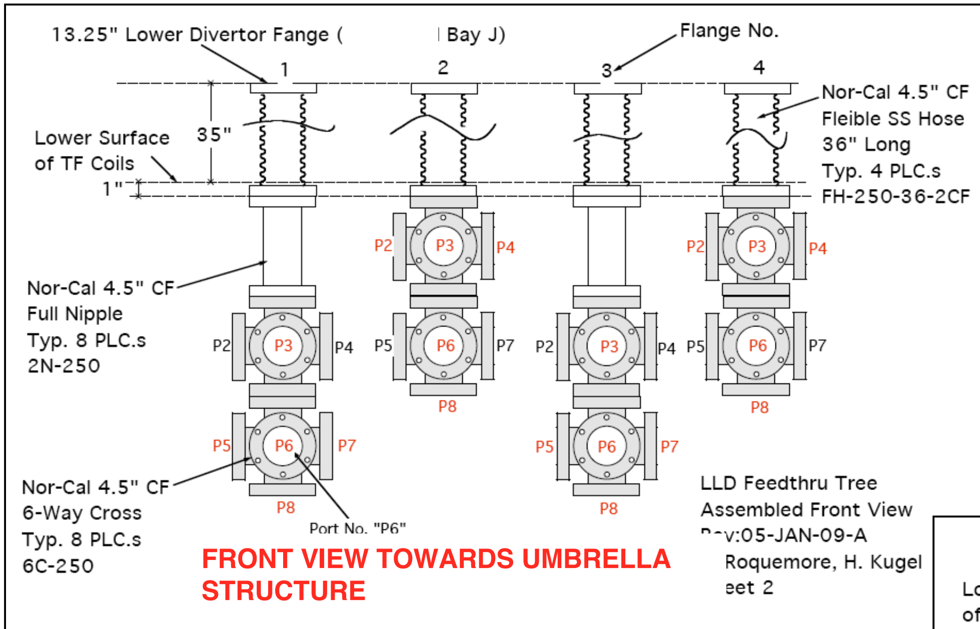


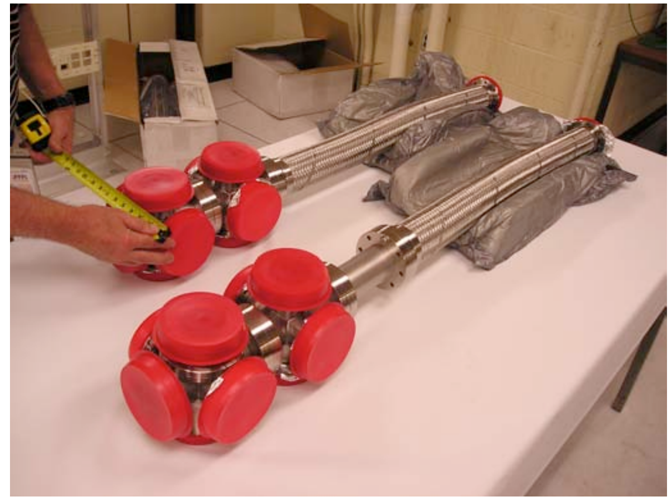


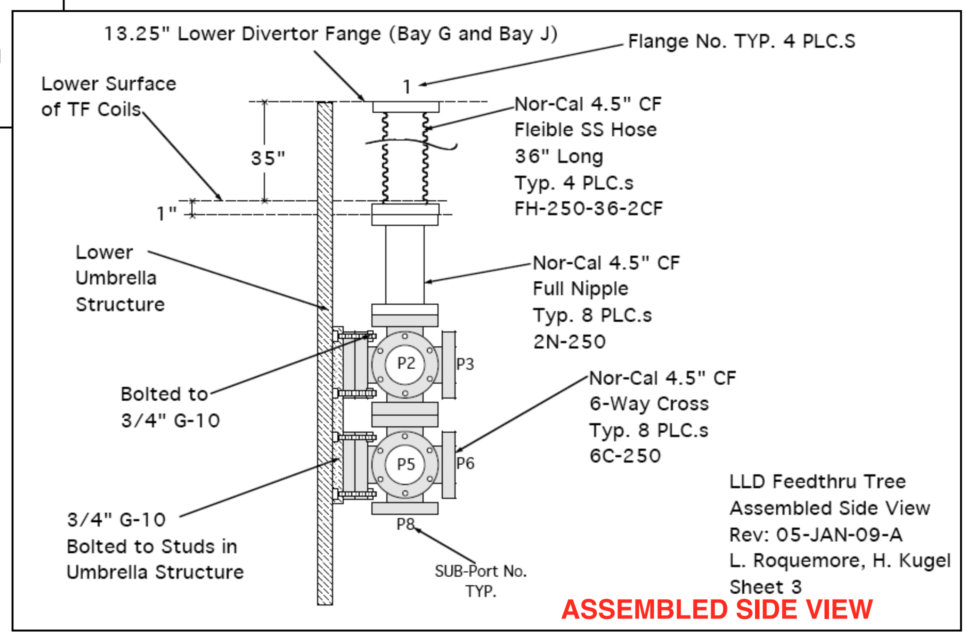
- Temperature rise of ~250 °C/shot assumes 10 MW/m^2 for 1s
- Thermal reservoir was small compared to actual vessel tile
- Only several probes will see maximum heat from strike point
- If large ratcheting is observed, strike point can be moved to allow longer cooling time

J.Timberlake, PPPL

Large number of LLD sensors requires careful layout of signal cables to numerous "trees" for feedthoughs





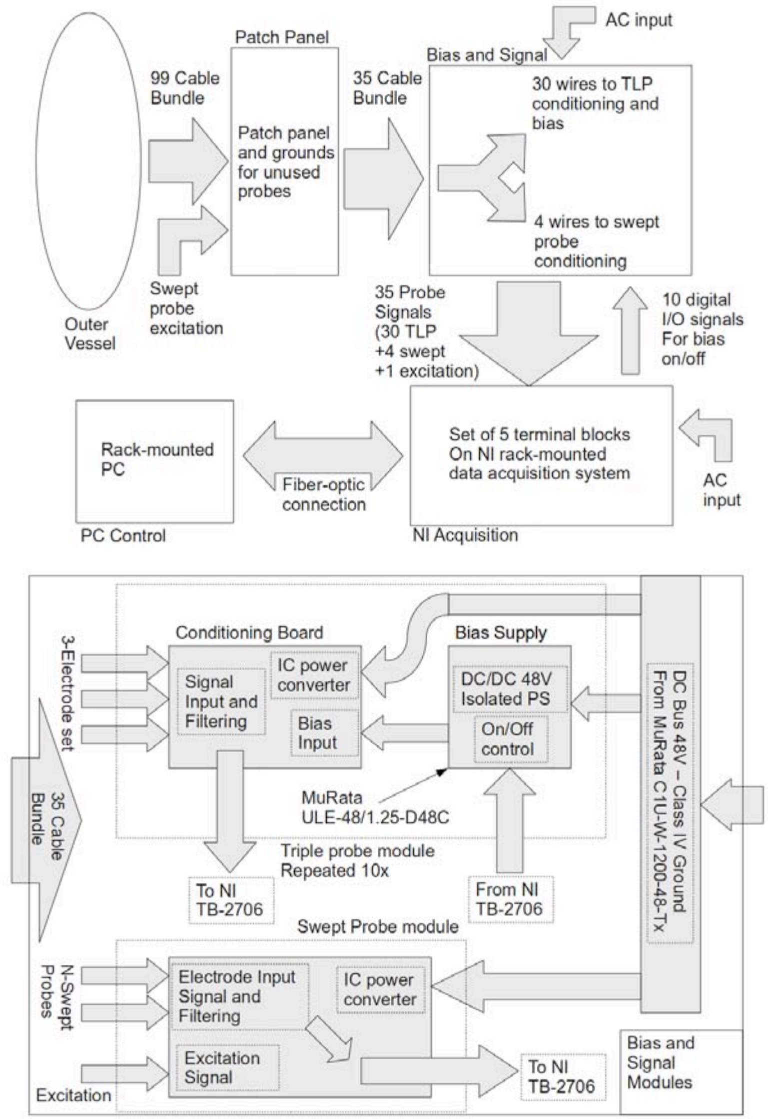


- Feedthru Tree at Bay-J provides sufficient electrical feedthru capability for 20 connectors (32- and 41-pin).
- An additional one feedthru at Bay-E uses existing 2-3/4" CF.

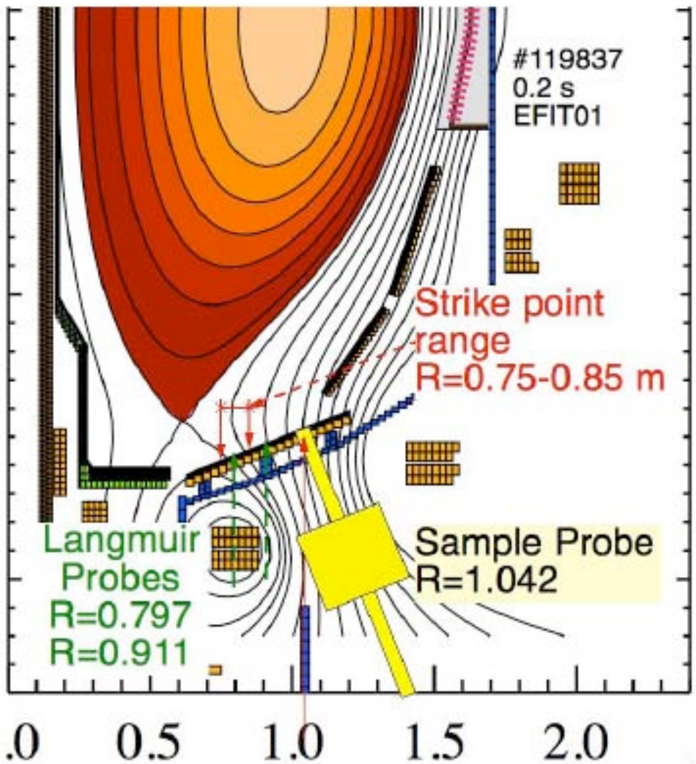
New probe electronics will permit continuous triple-probe operation

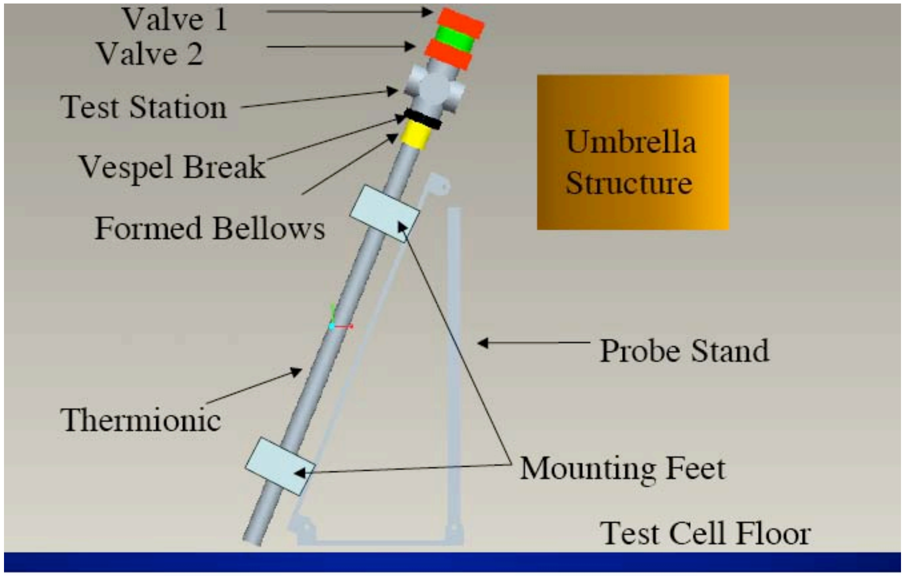
- Triple probe interpretation will be supplemented by single-tip tile probe sweep characteristics
  - single tip probes can provide ion saturation current data
  - existing probe hardware can be migrated to new rack to be used with single tip probes
- Initial implementation provides for 10 triple-probe sets
  - future upgrades will expand probe electronics
  - wiring scheme will allow external (to vessel) selection of which probes to operate
- Joint U-Illinois and PPPL collaborative design effort and production

M.A. Jaworski, U-Illinois



Divertor Region Sample Probe provides in-situ surface analysis capability

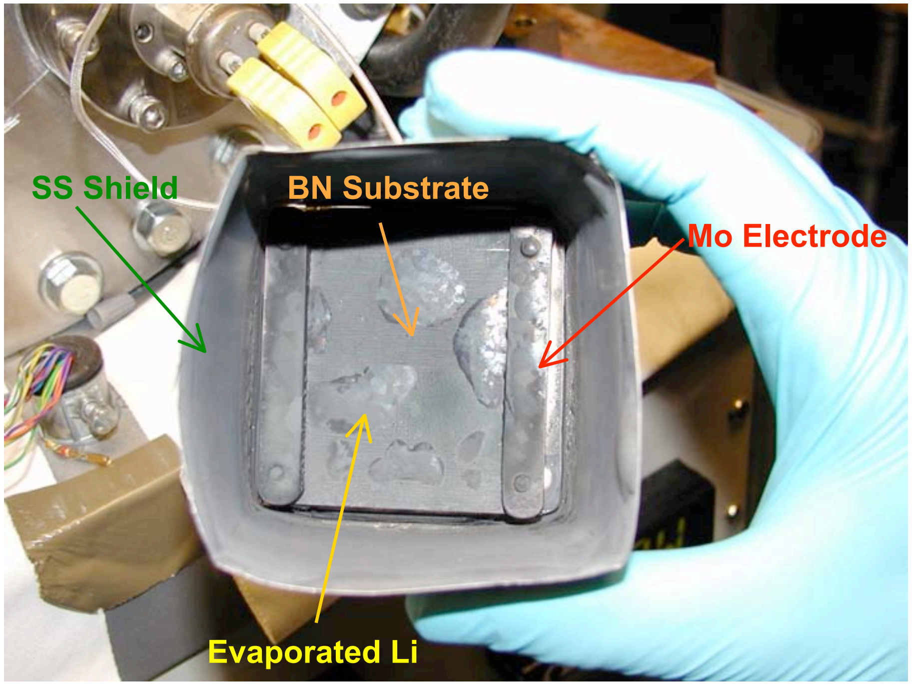




- Operating diagnostic to be upgraded by Purdue Univ. collaboration to provide in situ sample analysis capability
- Complements continuous monitoring of surface coatings with three quartz deposition monitors

Diagnostic to measure thickness/quality of lithium coating is in development

- Concept involves a potential sample probe insert that will consist of two electrodes embedded in an insulating material, likely BN
- As lithium is deposited, a resistive path forms
  - following basic resistivity assumptions, resistivity will change as lithium thickness increases
- Resistivity will change as lithium becomes saturated with deuterium, carbon, etc
- Characterization experiments are in process with a prototype tile to determine a calibration curve for various lithium thicknesses and hydrogenic and impurity deposition profiles



Summary and future plans

<u>Summary</u>

- FY09 goals of developing strike point control and using it to create an intermediate-δ discharge were achieved
  - EFIT data show strike points come within ~1 cm of request
- Profile and equilibrium data were obtained for new discharge shape
  - favorable results for ion temperature, WMHD, and beta observed
- Progress was made in fueling discharge with SGI

<u>Future Plans</u>

- Examine equilibria and resolve discrepancy between peak heat flux and strike point locations using LRDFIT, TRANSP, etc
- Analyze data with UEDGE to determine recycling and pumping behavior
- Utilize new diagnostics (LP array, LLD camera system, 2-color IR cameras, Lyman-α array, thickness diagnostics – see PP8.046 [Kaita] for more on diagnostics) to characterize discharge under LLD conditions in FY10