NSTX

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Diagnostics for Evaluating Performance of NSTX Liquid Lithium Divertor*

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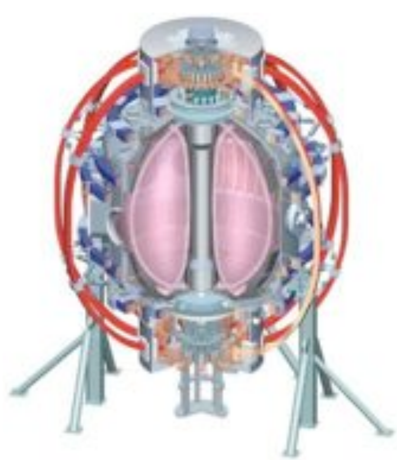

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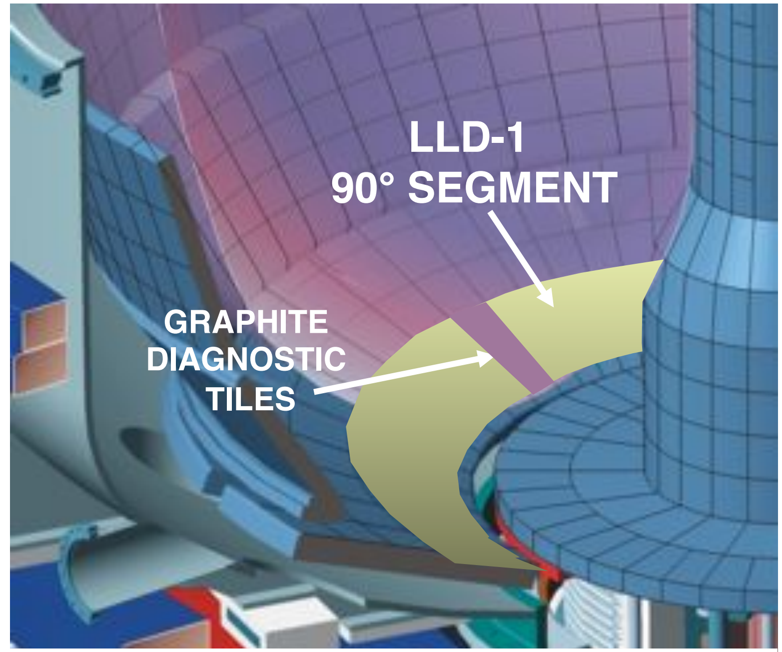
Abstract

A Liquid Lithium Divertor (LLD) is being installed on NSTX to investigate particle control and power handling with liquid lithium as plasma-facing component (PFC). The LLD is expected to provide a low-recycling plasma-facing component (PFC). To study the effects of such a PFC on plasma performance, a variety of edge measurements are required. Since its surface is highly reflective at visible wavelengths, a Lyman-alpha detector array will be used to monitor the recycling. To understand changes in edge transport, electron temperature and density measurements will be made with Langmuir probes mounted in PFC's near the LLD, and the edge sightlines of a multipoint Thomson scattering system. A frequency-scanning reflectometer will also provide scrapeoff layer electron density profiles. The LLD response to heat loads will examined with infrared cameras and thermocouples. Diagnostics are also needed to measure the erosion and codeposition of lithium. They include quartz deposition monitors and a retractable probe for exposing samples to the plasma.

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** - 0.01 cm Mo plasma-sprayed on 0.02 cm SS brazed to 1.9 cm Cu
- **Li Loading** - two lithium evaporators



- Each toroidal section electrically grounded to vessel at one mid-segment location to control eddy currents
- Sections attached to divertor copper baseplate at each corner with fasteners providing structural support and 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 and current sensors

See poster PP8.0044 for details

H. Kugel, PPPL

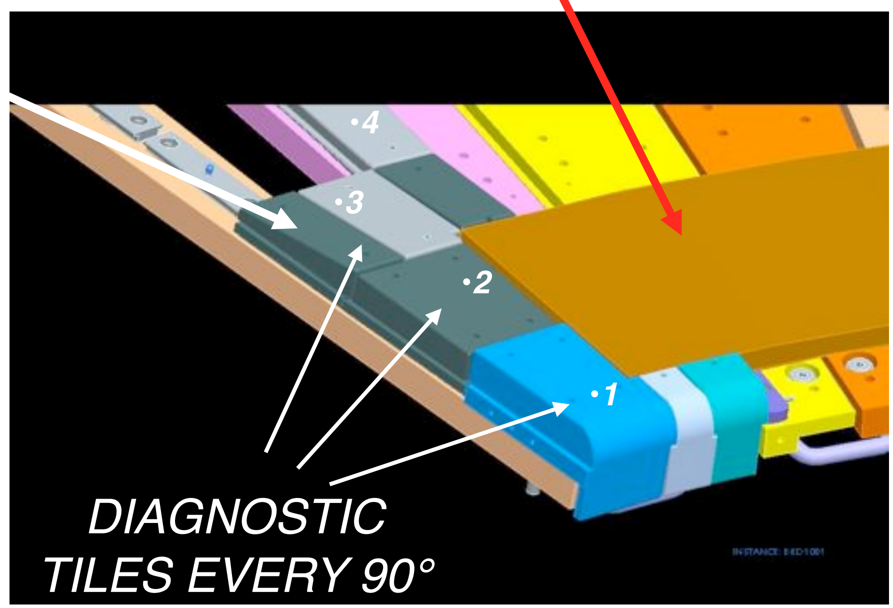
Diagnostic tiles located every 90 degrees around LLD

•<u>Listed CCW starting at Bay H</u>

- GAP-H Tile
  - 5 magnetic sensors
  - 2 TC (in IR Camera FOV)
- GAP-E Tile
  - 2 BEAP bias electrodes
  - 2 TC (in IR Camera FOV)
  - 5 Langmuir Probes
- GAP-B Tile
  - 99 Langmuir Probes
    (33 sets of 3 toroidal rows)
    [triple (UIUC) and single probes]
- GAP-K Tile
  - 2 BEAP bias electrodes
  - 5 Langmuir Probes
  - 2 TC (in IR Camera FOV)

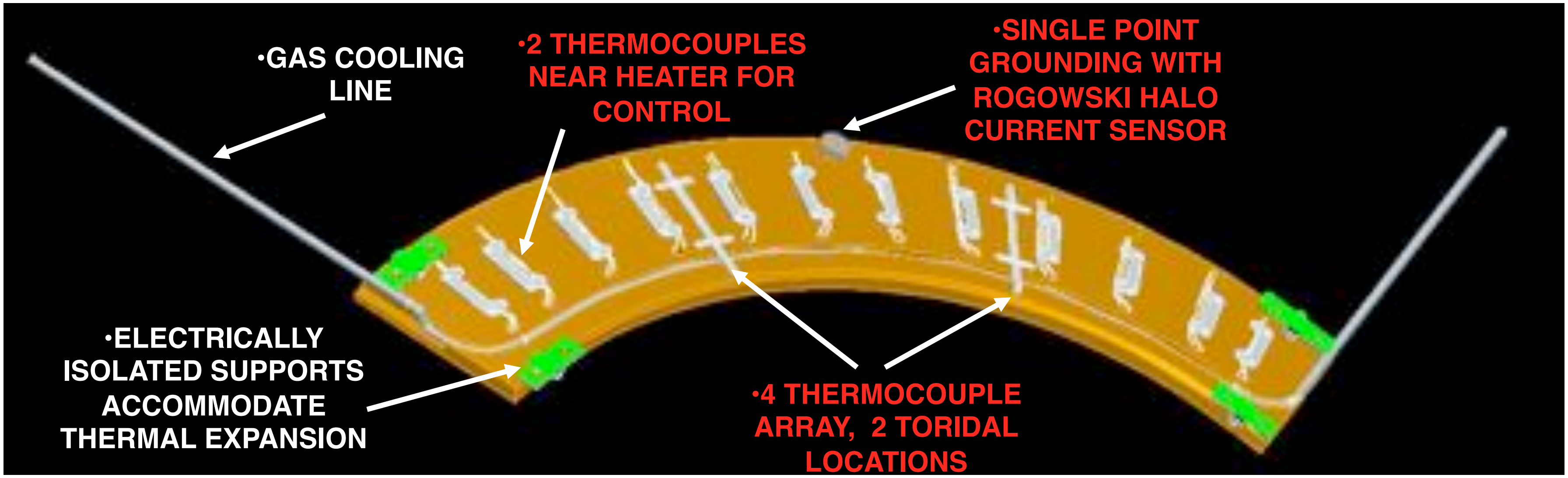
Halo Current Shunt Tiles
- radial array of 2, every 60°

The plasma surface of the substrate is clad with 0.01 cm of vacuum flame sprayed Mo on a 0.03 cm stainless steel barrier brazed to the 2.2 cm copper substrate.



Bottom View of LLD-1 Copper Substrate Plate Showing Controls and Sensors

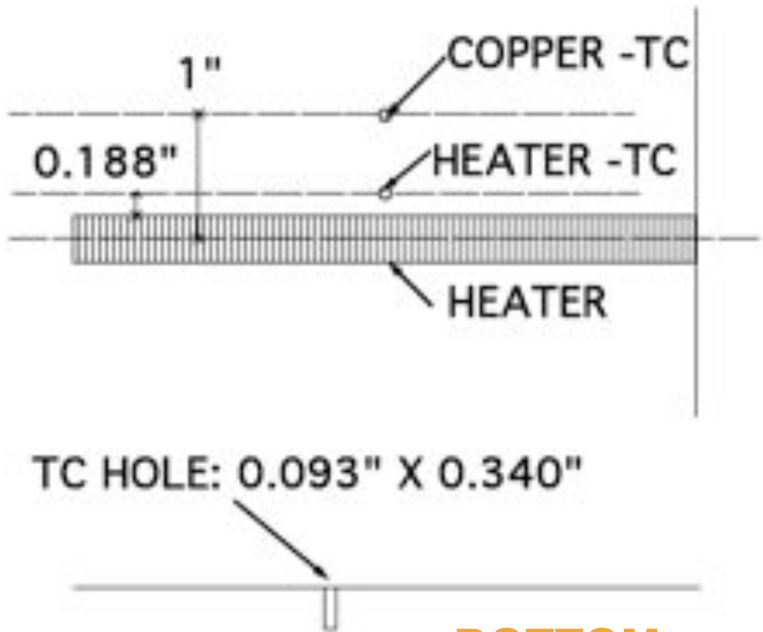
• Bottom View of LLD-1 Copper Plate Showing Thermocouples and Rogowski Coil



- 12 heaters (240 V) each with TC mounted ~0.25" from heater for control.
- 12 additional TC mounted 1" from each heater for spare and redundancy.
- 2 strips of 4 TC each for monitoring torodial and radial temperature variations.
- 1 Center post halo current Rogowski coil for monitoring JxB effects.

LLD Temperatures Monitored with Type-K Thermocouples

- Initial design used heater model with embedded thermocouple (TC) for temperature control
- Heater vacuum testing encountered electrical shorts between the TC and heater leads and variable resistance between TC leads and heater enclosure.
- New design adopts heater model without embedded TC and uses TC embedded in copper next to heater for control
- TCs uses proven NSTX NBI calorimeter and armor designs
  - coated with high temperature, silver-based conductive epoxy and inserted into 0.093 inch ID hole in copper
- Graphite diagnostic tiles to have TCs for IR camera calibration and monitoring temperatures during LLD operation

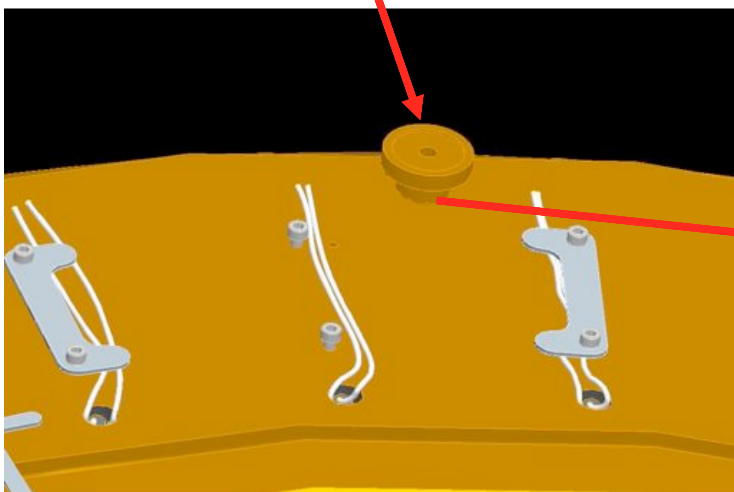


- BOTTOM SIDE OF COPPER

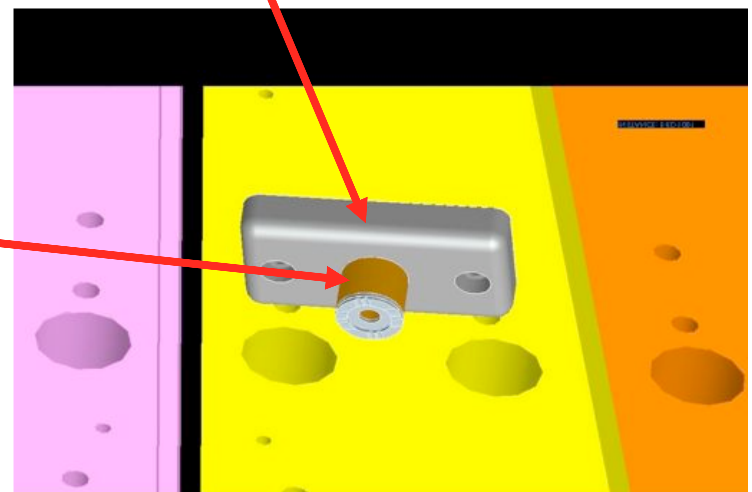
Each LLD-1 Segment Has Single Point Ground With Rogowski Halo Current Sensor

- Single point grounding post to be surrounded by Rogowski halo current sensor

- Clamp fastens Grounding Post to divertor copper plate



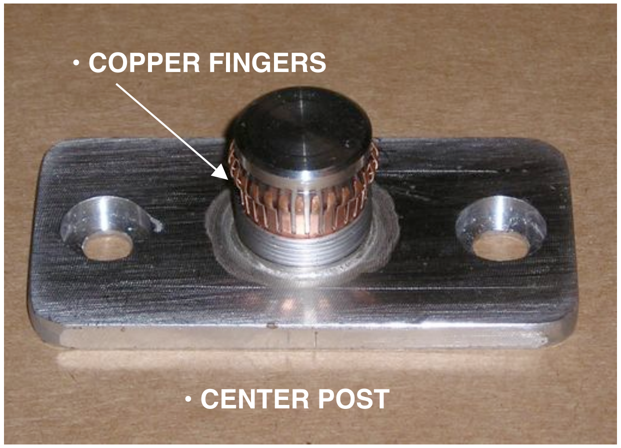
• LLD-1 Bottom View

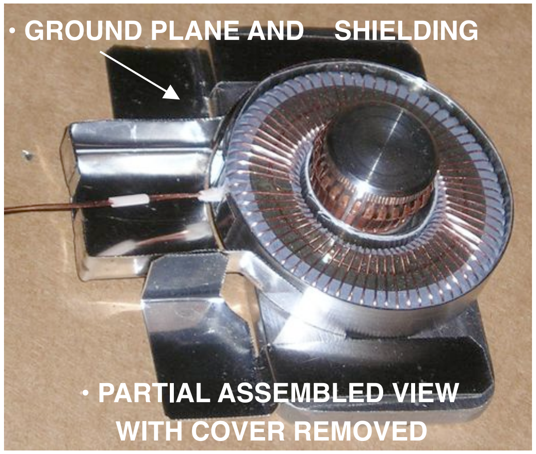


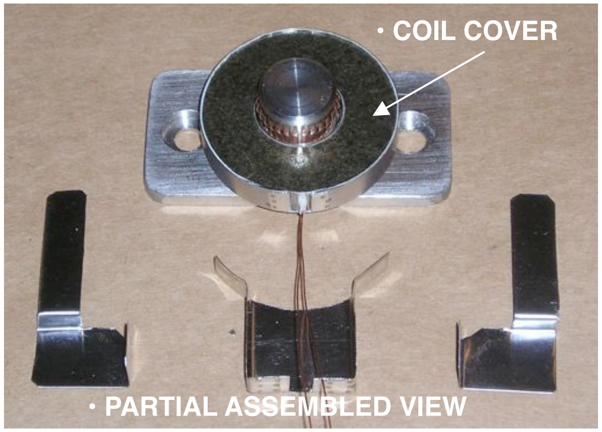
• Lower Divertor Copper Plates

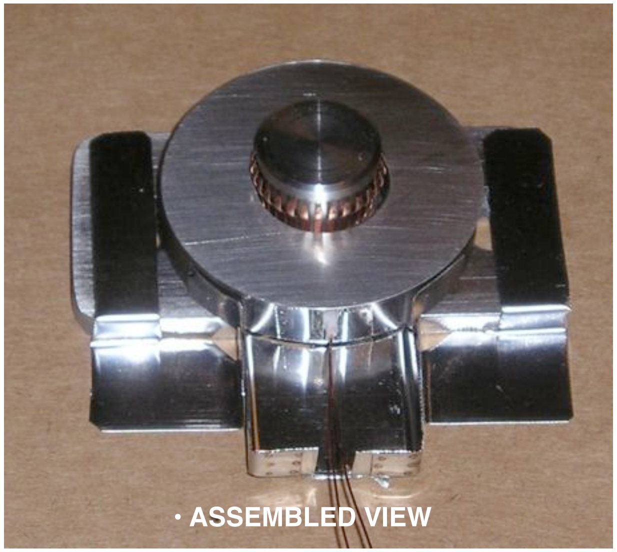
S. Gerhardt, L. Guttadora, and R. Ellis

Photos of Rogowski Coil Assembly





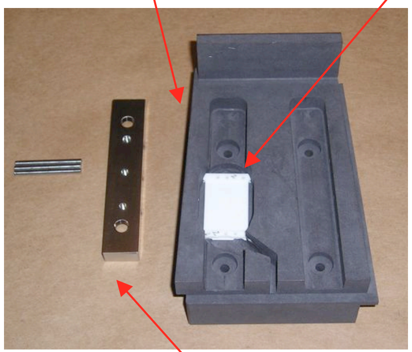


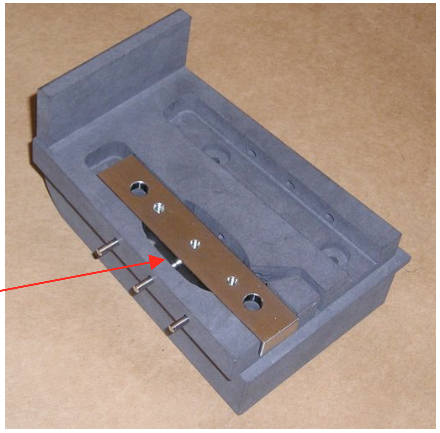


L. Guttadora

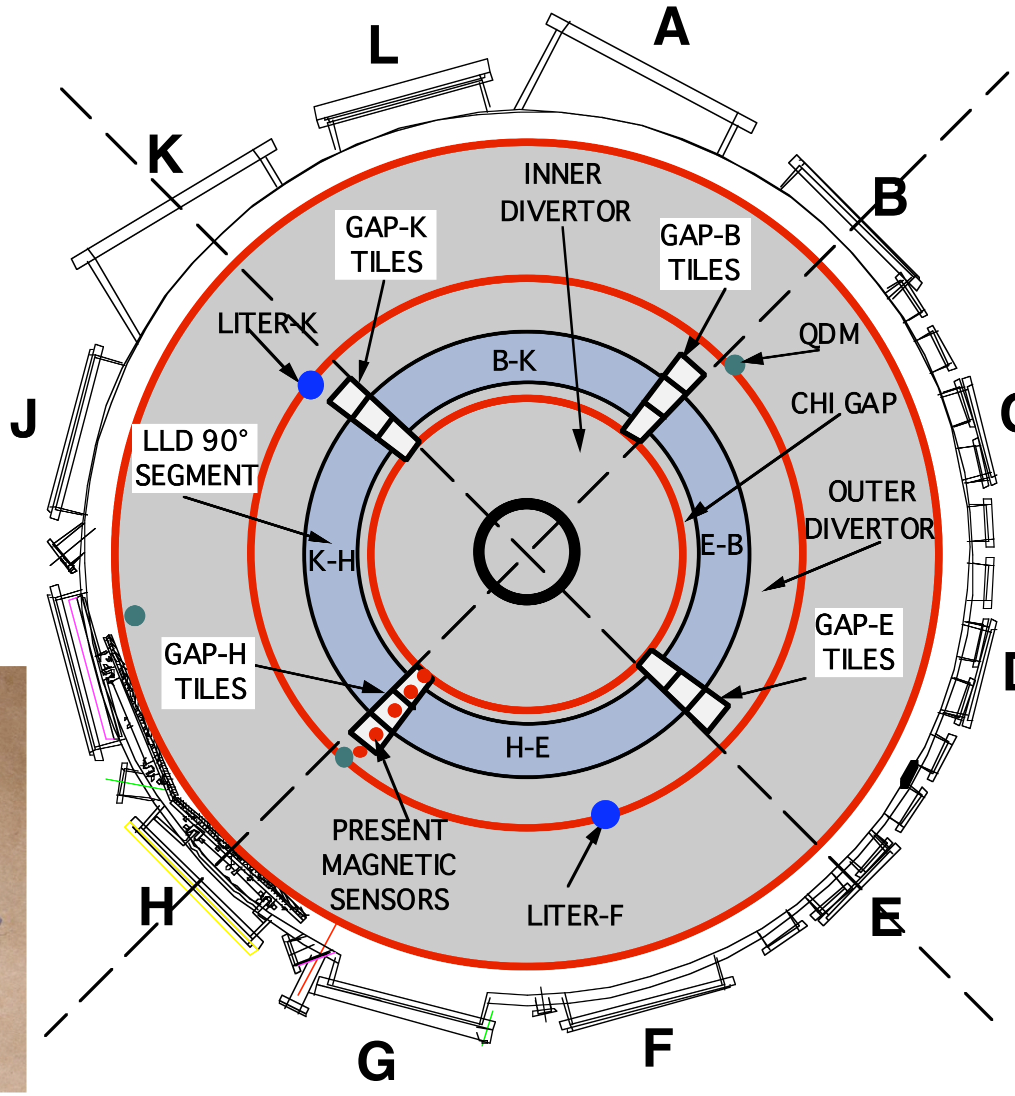
LLD-1 Segments Are Oriented Relative to Present Bay-H Magnetic Sensors

- **Present 2D magnetic sensors at Bay H define start of LLD toroidal orientation**
- **Three of original tiles and sensors replaced with new LLD tiles and sensors.**





• NEW TEE-BAR STYLE



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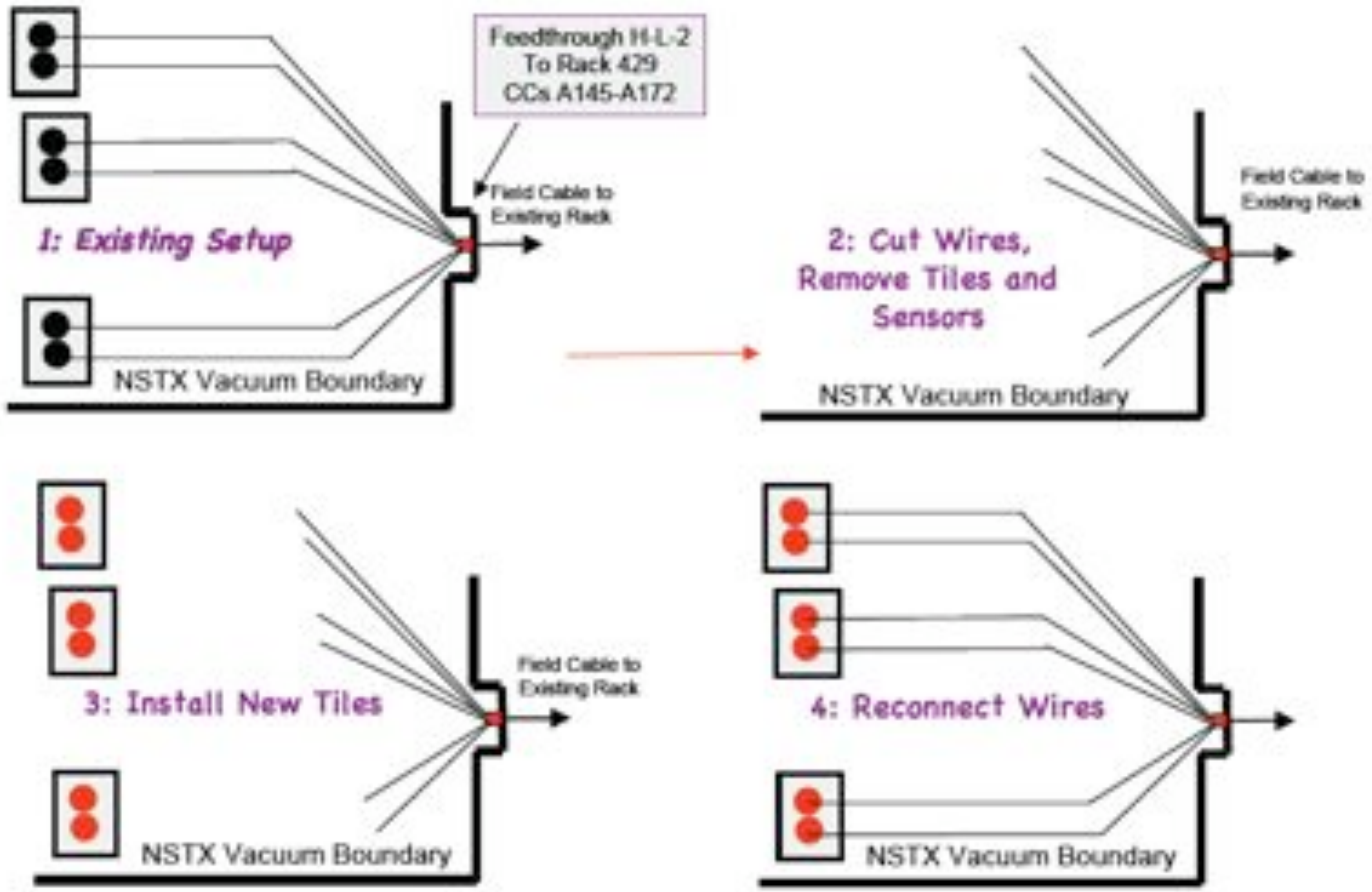
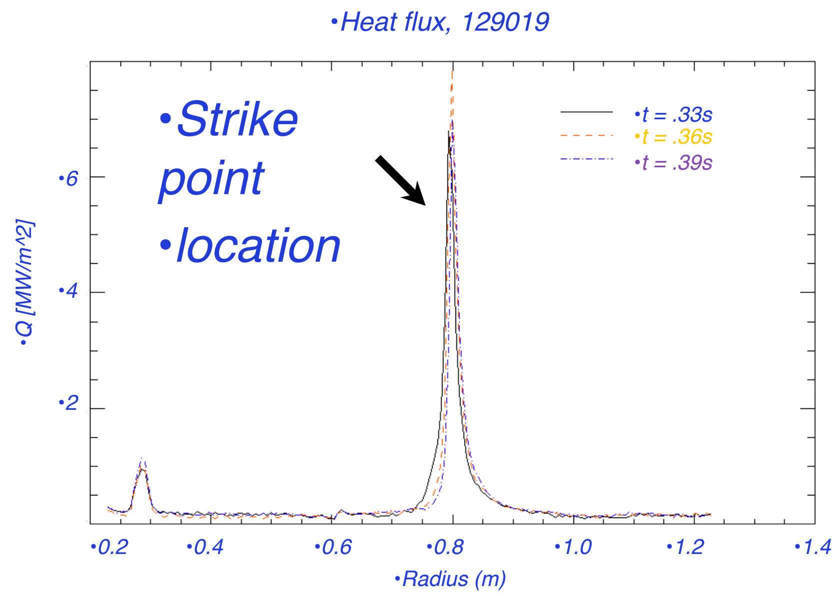
Elementary Bay-H 2D Sensor Schematic and Procedure

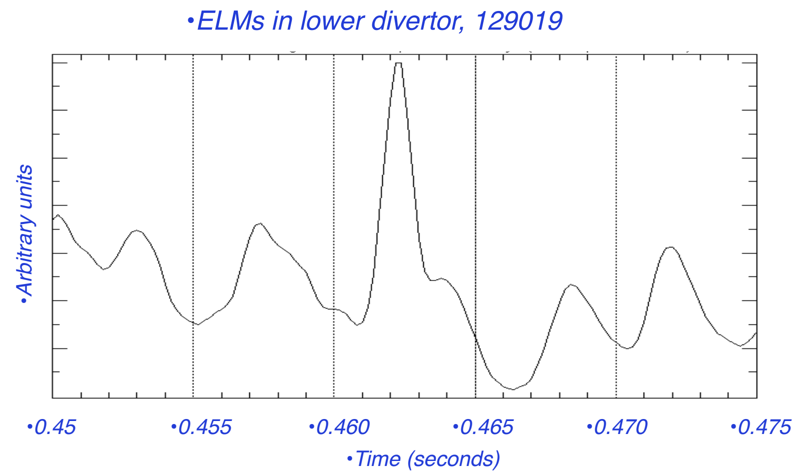


S. Gerhardt, L. Guttadora, and R. Ellis

Physics Requirements for the Langmuir Probe Array

- **Poor coverage of 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**



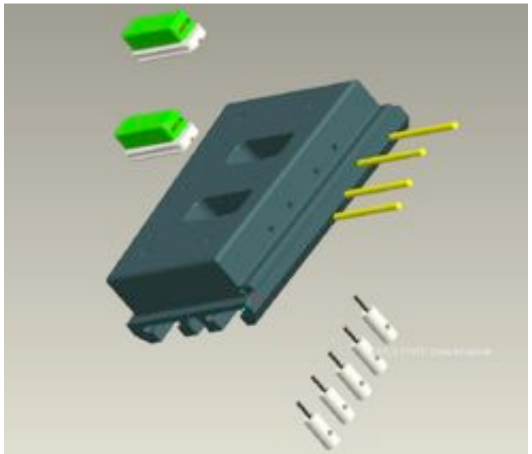


Triple Langmuir Probe Array to Provide Edge Data with High Spatial Resolution

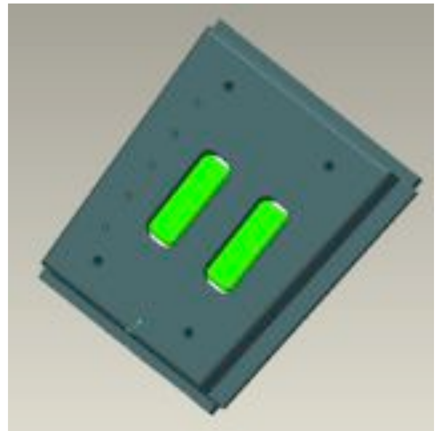
- **Radial array in 33 sensor triple-probe configuration to be used for edge temperature and density measurements**
- **Probes based on MAST design with MACOR cassette containing closely-spaced probes embedded in carbon tile**
- **Close spacing of probes to enable high-resolution in strike point region**
  - **probe heads are rectangles with 2.5 mm radial x 7 mm toroidal extent**

See poster PP8.00045 for details

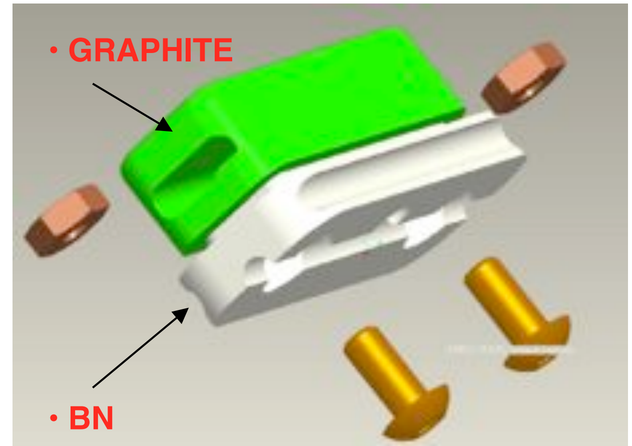
Bias Tiles for Testing Ryotuv/Cohen Concept for Controlling Divertor Strike Point Location



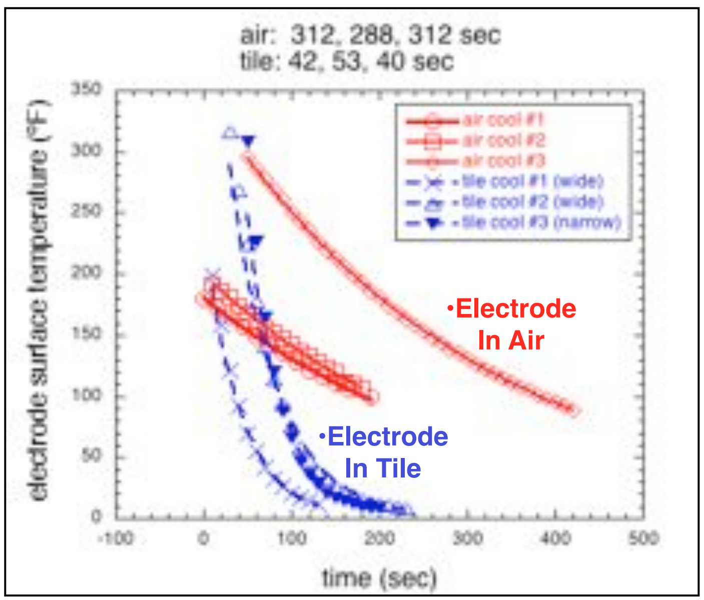
• Bay-E Toroidal Electrodes



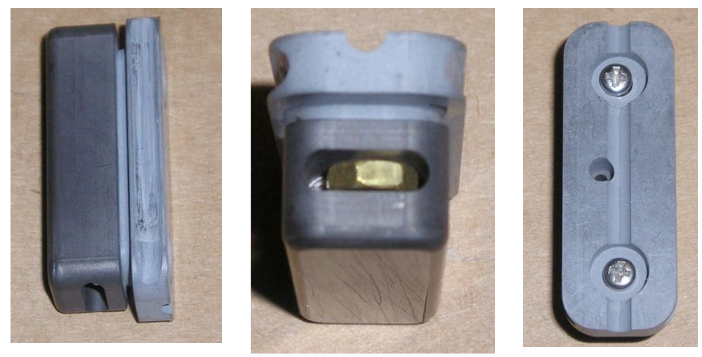
• Bay-B Radial Electrodes



• Probe Head



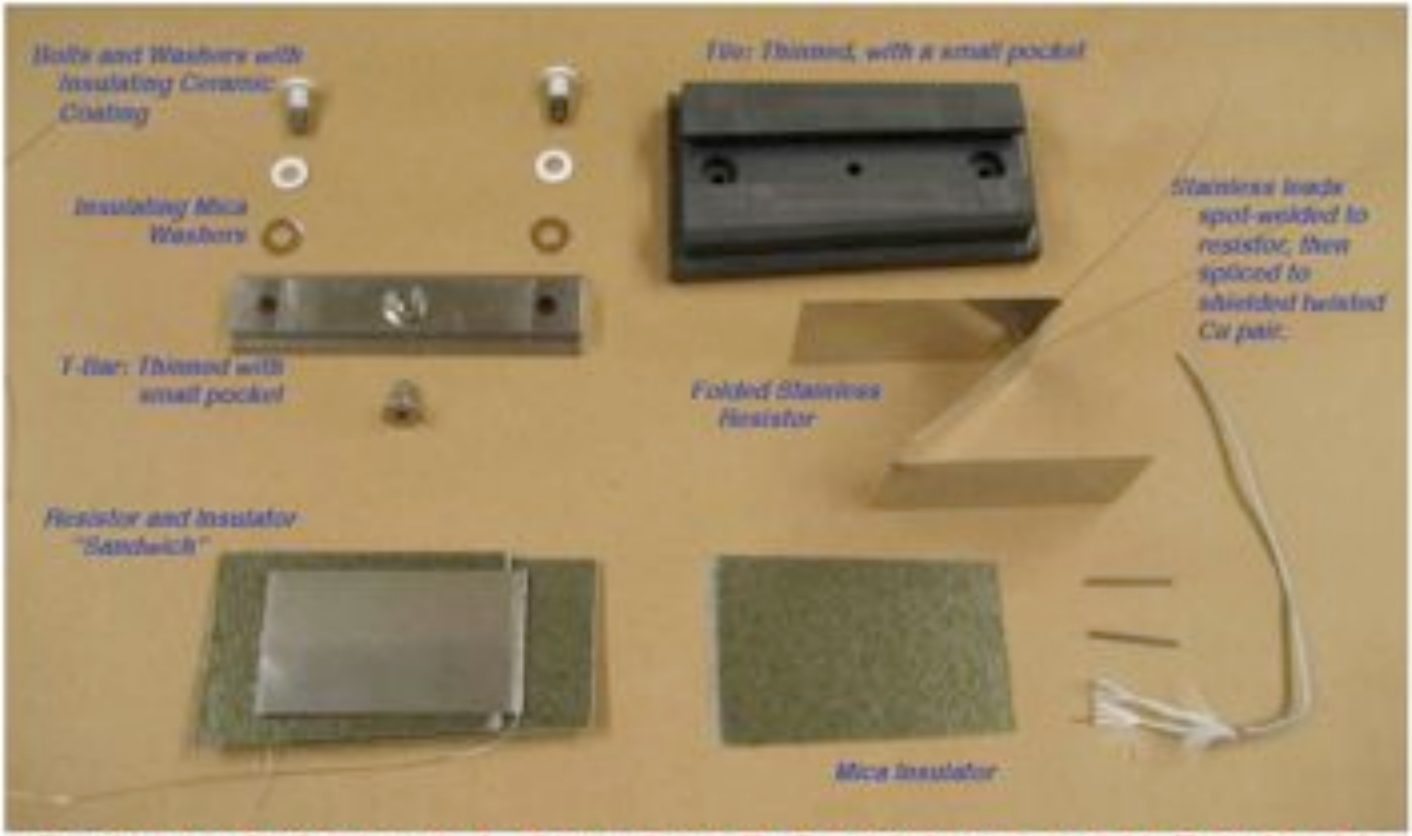
• Cool-down Time Constant in Air ≤60s



• **Uses existing BEaP power supplies and controls.**

S. Zweben

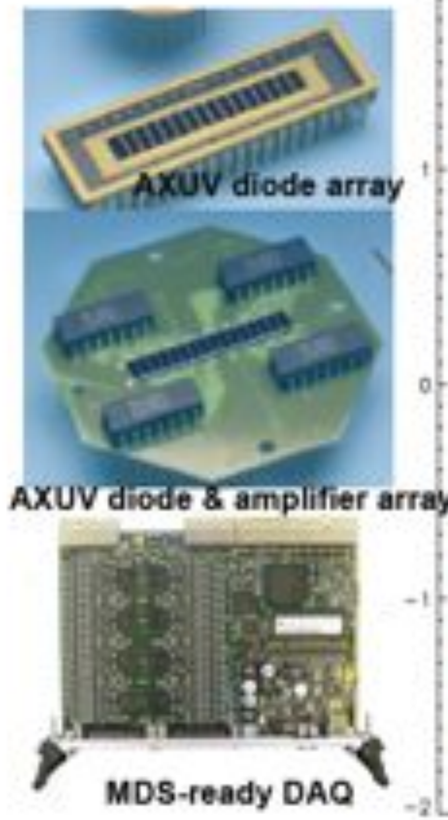
Halo Current Shunt Tiles in Outer Divertor Tile Rows #3 and #4 Every 60°

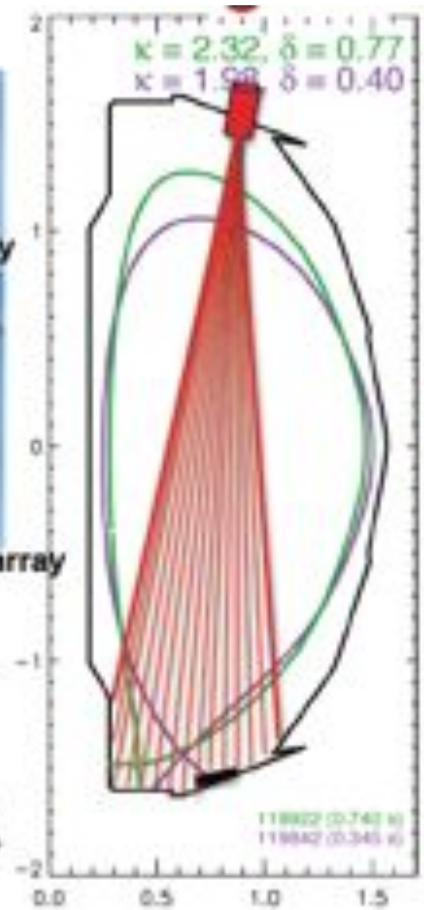


Design by S. Gerhardt, L. Guttadora, E. Fredrickson, and H. Takahashi

Lyman-α Diode Arrays to be Used for Observing Effects of LLD on Recycling

- Mirror-like lithium surface will complicate interpretation of visible (400-750 nm) spectroscopic diagnostics
- AXUV diode arrays with bandpass filters measure Ly-α n=1-2 H/D transition at 121.6 nm, where reflections are negligible
- 16-20 channel diagnostic can be assembled from off the shelf components
- One array will be fielded in FY09 at Bay G upper divertor port



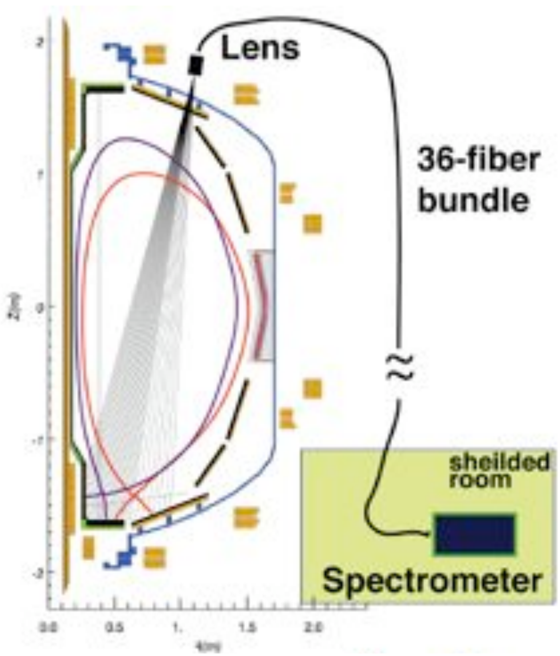


V. Soukhanovskii, LLNL

Visible Diagnostics for Divertor Region Include New Spectrometer

Divertor spectrometer to address high priority Boundary Physics goals:

- Divertor ion source characterization
- Divertor ion sink characterization
- Divertor ion temperature measurements
- Applications
  - Near-IR spectroscopy for ITER
  - LLD impurity profile measurements
  - Divertor and edge during HHFW

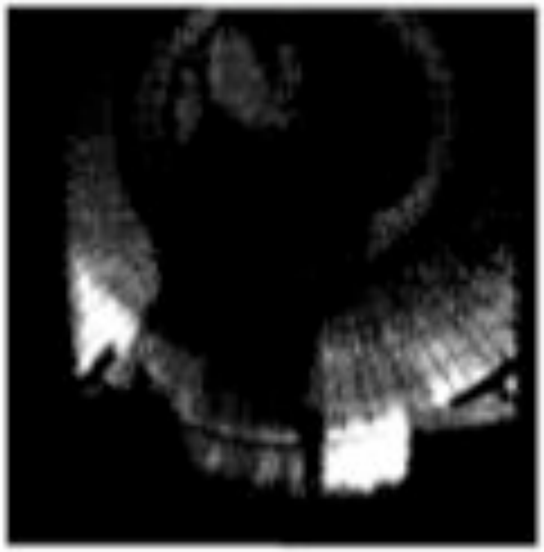


- 2 Divertor Views: Downward from Bay-C top and Bay-B tangential divertor view

V. Soukhanovskii

Camera System to Allow View of All Four LLD Segments and Intervening Diagnostic Tiles

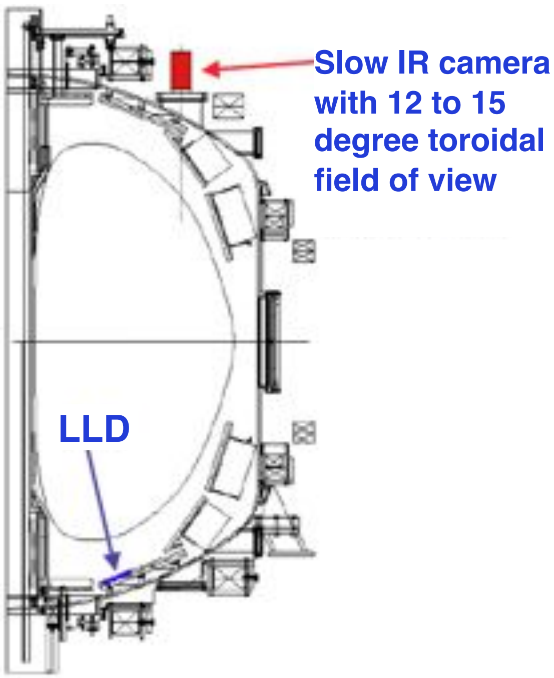
- **Two Phantom v710 cameras to provide full toroidal views of the LLD in the visible and near IR**
  - **can detect hot spots of >500° C on a 50μs timescale and correlate bulk temperature with plate thermocouples at 10 Hz**
  - **filters to allow monitoring of visible Mo and Fe lines to look for erosion**
  - **visible inspection to aid in determination of surface quality**
    - **reflectance, impurity blobs, etc**
- **Views cover diagnostic tiles to enable monitoring of heating and lithium coverage**
- **High speed of cameras to allow observation of turbulence at divertor surface**

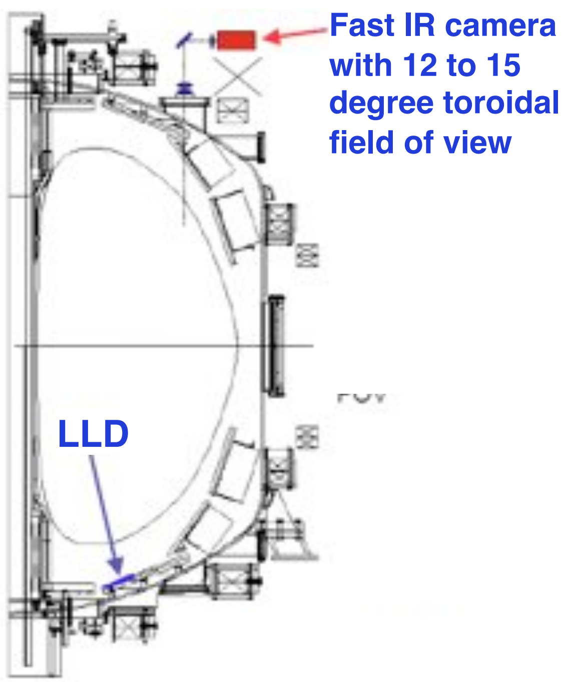


View of NSTX Divertor Region
R. Maqueda (NOVA Photonics)

IR Cameras Permit Imaging of Equilibrium and Transient LLD Conditions

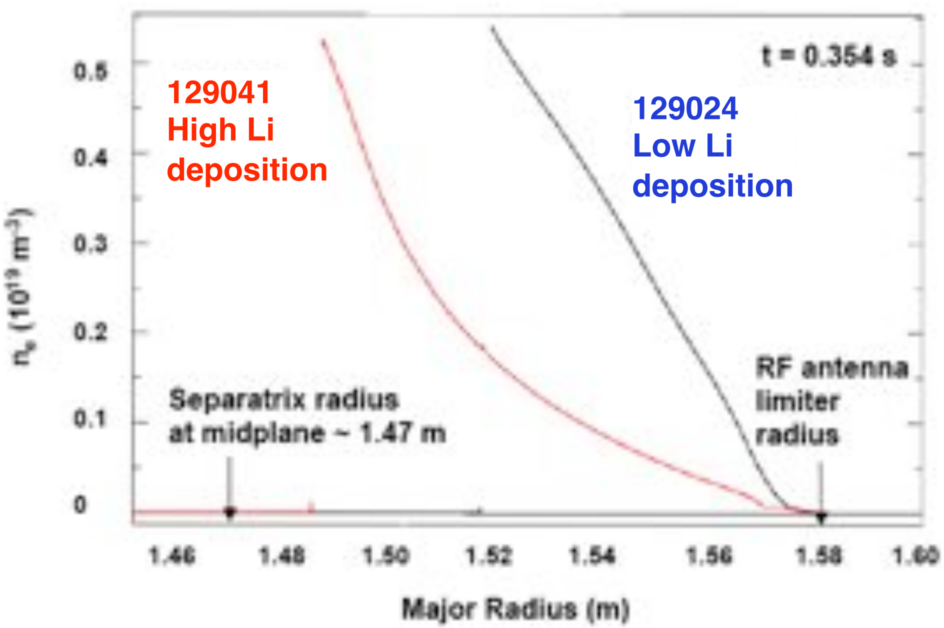
- **Slow IR camera to be used for determining equilibrium heat flux profiles**
- **IR camera with faster frame rate to be used for visualizing variations in heat flux during ELMs and other transient phenomena**
- **“Two-color” capability planned for addressing uncertainties in emissivity of LLD surface**

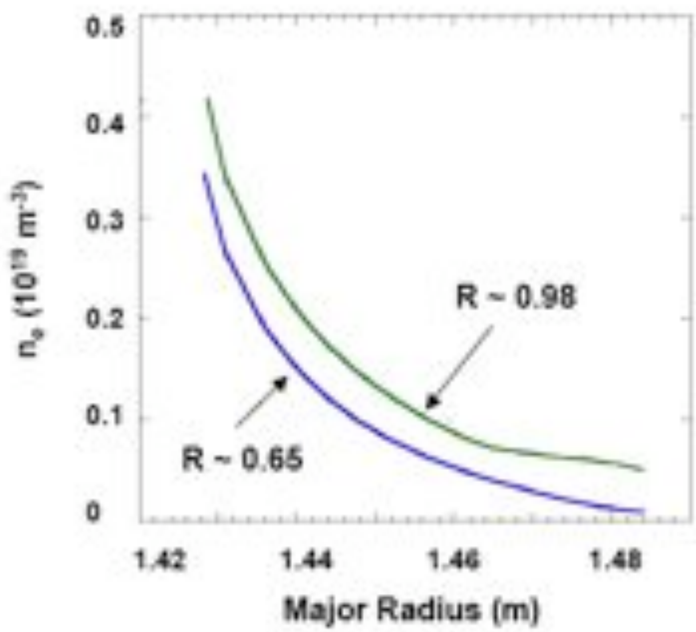




R. Maingi, L. Roquemore
R. Maqueda, D. LaBrie

Specialized Edge Diagnostics Include Scrapeoff Layer Interferometry to Determine Boundary Effects of LLD





- **Edge density profiles affected by lithium coatings**
  - Density profiles from UEDGE multi-fluid transport code calculations follow qualitative behavior of experimental data
  - Similar measurements and analysis to be performed with LLD plasmas

J. Wilgen

Summary

- Onboard sensors on each LLD 90° segment:
  - 12 TC embedded near the heaters for monitoring heater limits
  - 12 TC embedded in copper baseplate for monitoring heat transfer
  - 2 strips of 4 TC each for torodial and radial temperature variations
  - 1 Center Post halo current Rogowski for monitoring JxB effects
- Diagnostics in inter-segment graphite diagnostic tiles:
  - 2D magnetic sensor array and 2 TC
  - 99-sensor LP array with electronics for “triple probe” operation
  - 2 biased electrodes, 5 LP and 1 TC at two toroidal locations
- Diagnostics outboard of LLD
  - 2 halo current shunt tiles at 6 toroidal locations

- UV, visible, and IR cameras to be used for observing heating, recycling, and impurity behavior in vicinity of LLD

- Edge and scrapeoff layer diagnostics are critical to understand effects of LLD on NSTX plasmas