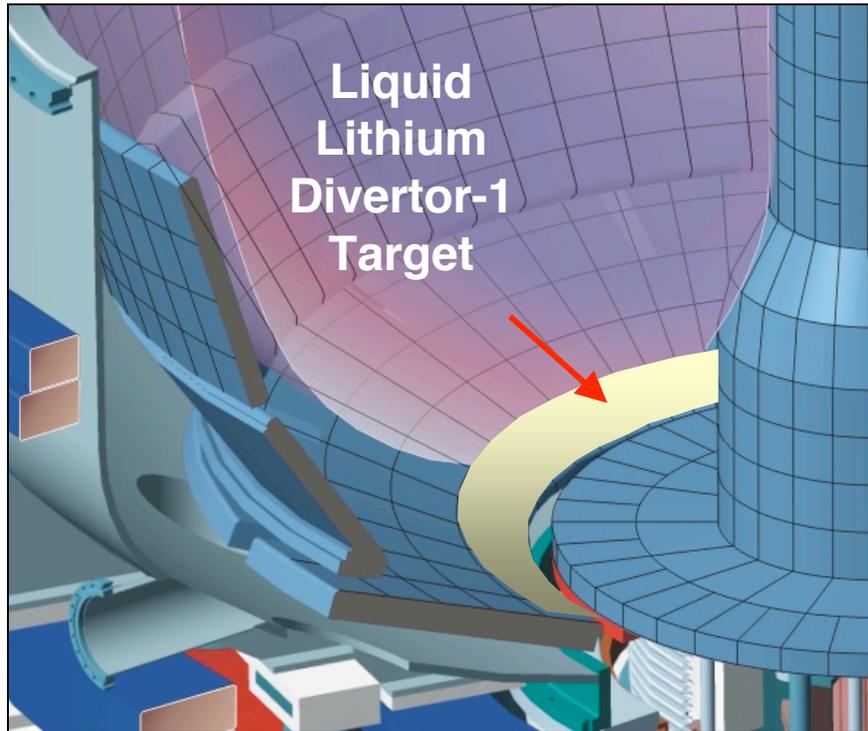


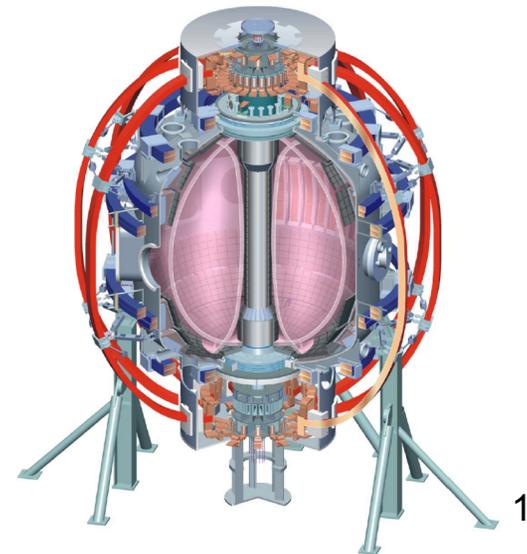
Supported by



Liquid Lithium Divertor-1 (LLD-1) on Outer Divertor

# *Final Design Review For LLD-1 Diagnostics*

H. W. Kugel and the LLD  
NSTX, SNL, UIUC Teams  
July 16, 2008



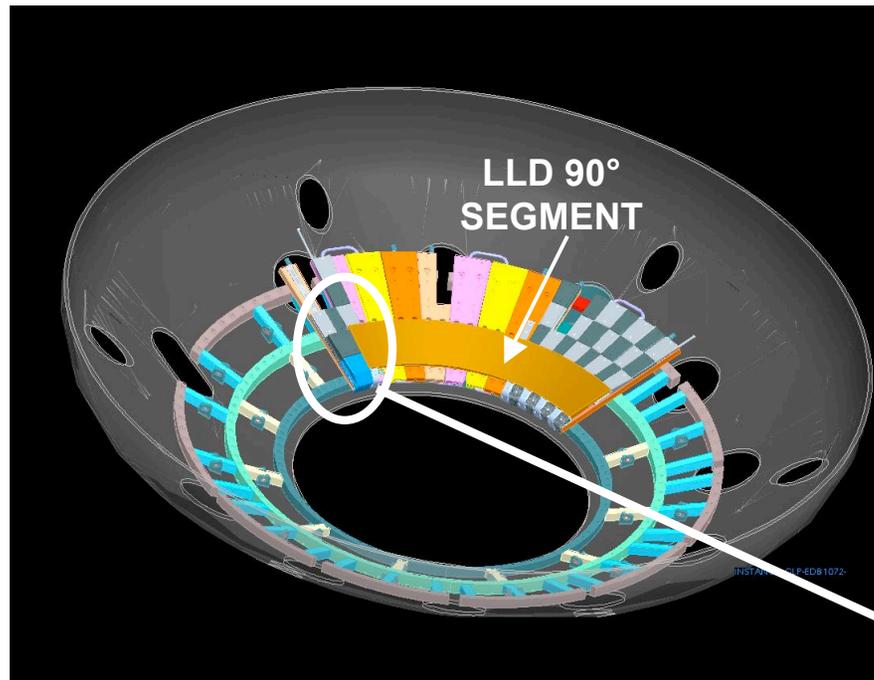
# Outline



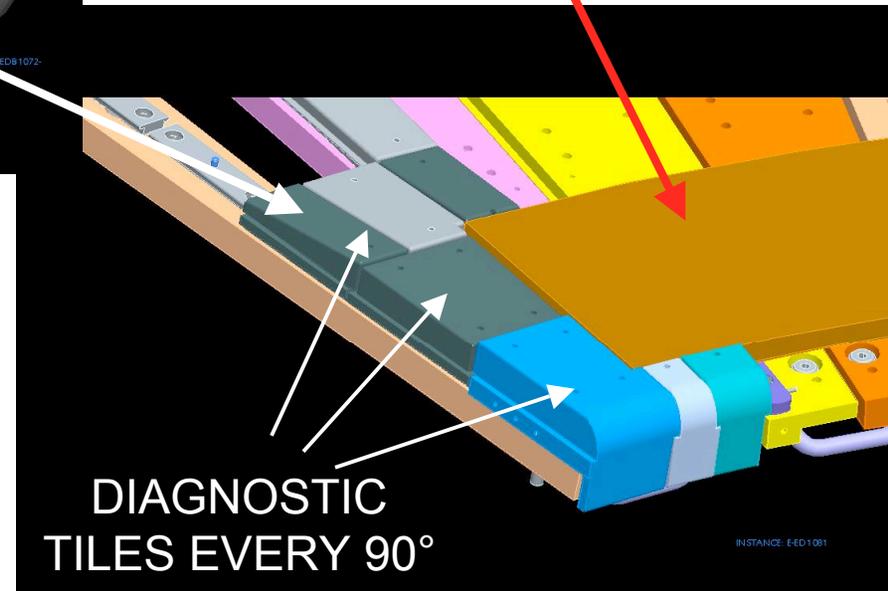
- **Presenters**

- **General configuration, H. Kugel**
- **Rogowski halo current sensors, S. Gerhardt**
- **Langmuir Probes,**
  - **Multi-probe Array, J. Kallman**
  - **UIUC signal conditioners for partial triple probe configuration, M. Jaworski**
- **Biased electrodes, S. Zweben**
- **IR Cameras, R. Maingi**
- **Lyman- $\alpha$  Diode Array, V. Soukhanovskii**

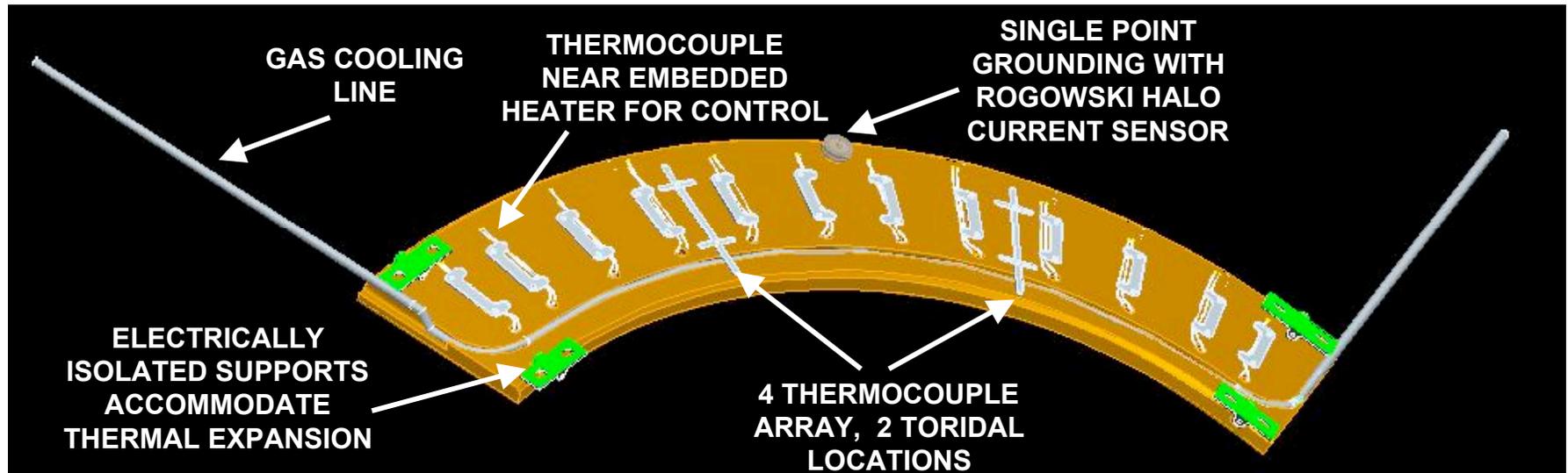
# Plasma Facing Views of the LLD-1 Copper Plate Substrate



- 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 1.9 cm copper substrate.

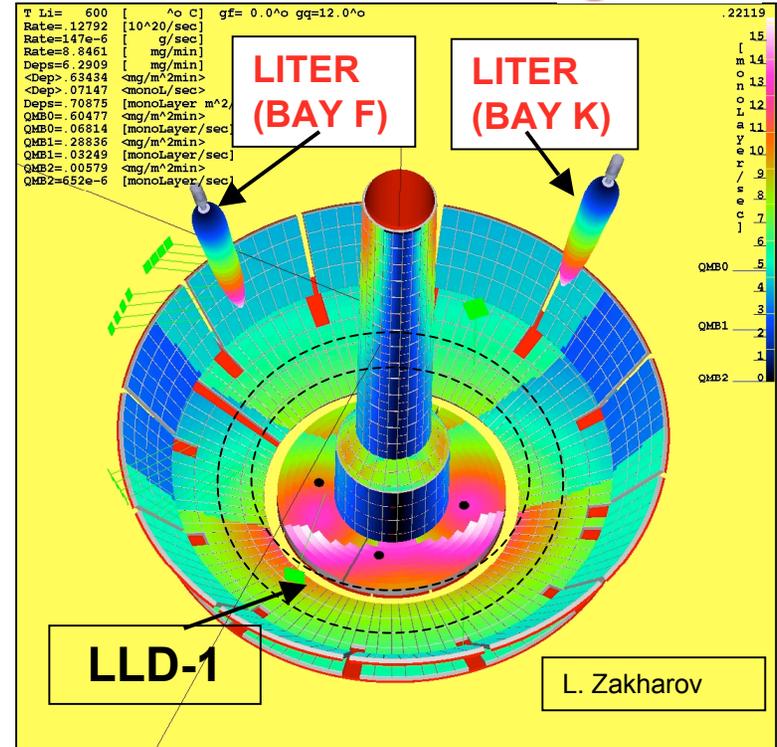
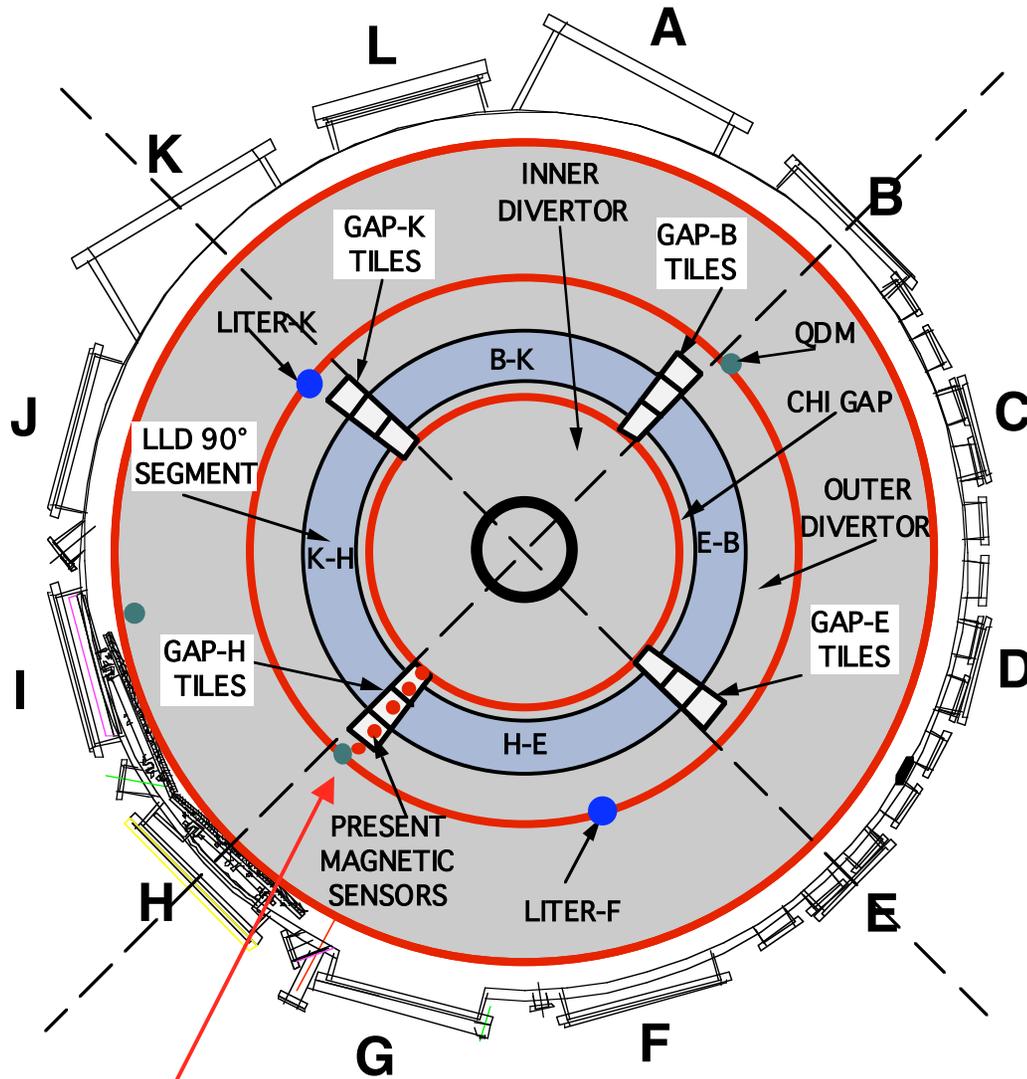


## Bottom View of LLD-1 Copper Substrate Plate Showing Controls and Sensors

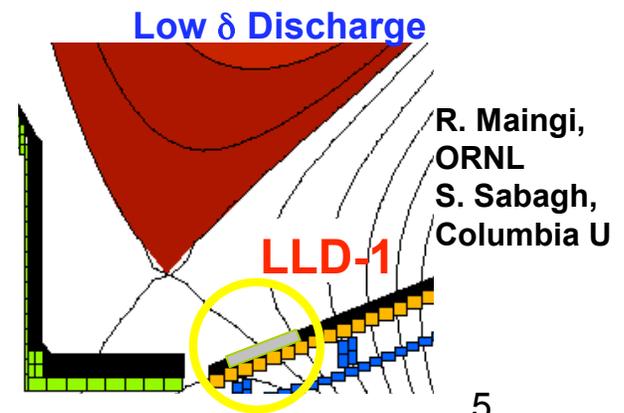


- 12 heaters (240v) each with embedded TC for monitoring heater limits
- 12 TC embedded in copper baseplate for monitoring heat transfer
- 2 strips of 4 TC each for monitoring torodial and radial temperature variations
- 1 Center post halo current Rogowski coil for monitoring  $J \times B$  effects

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



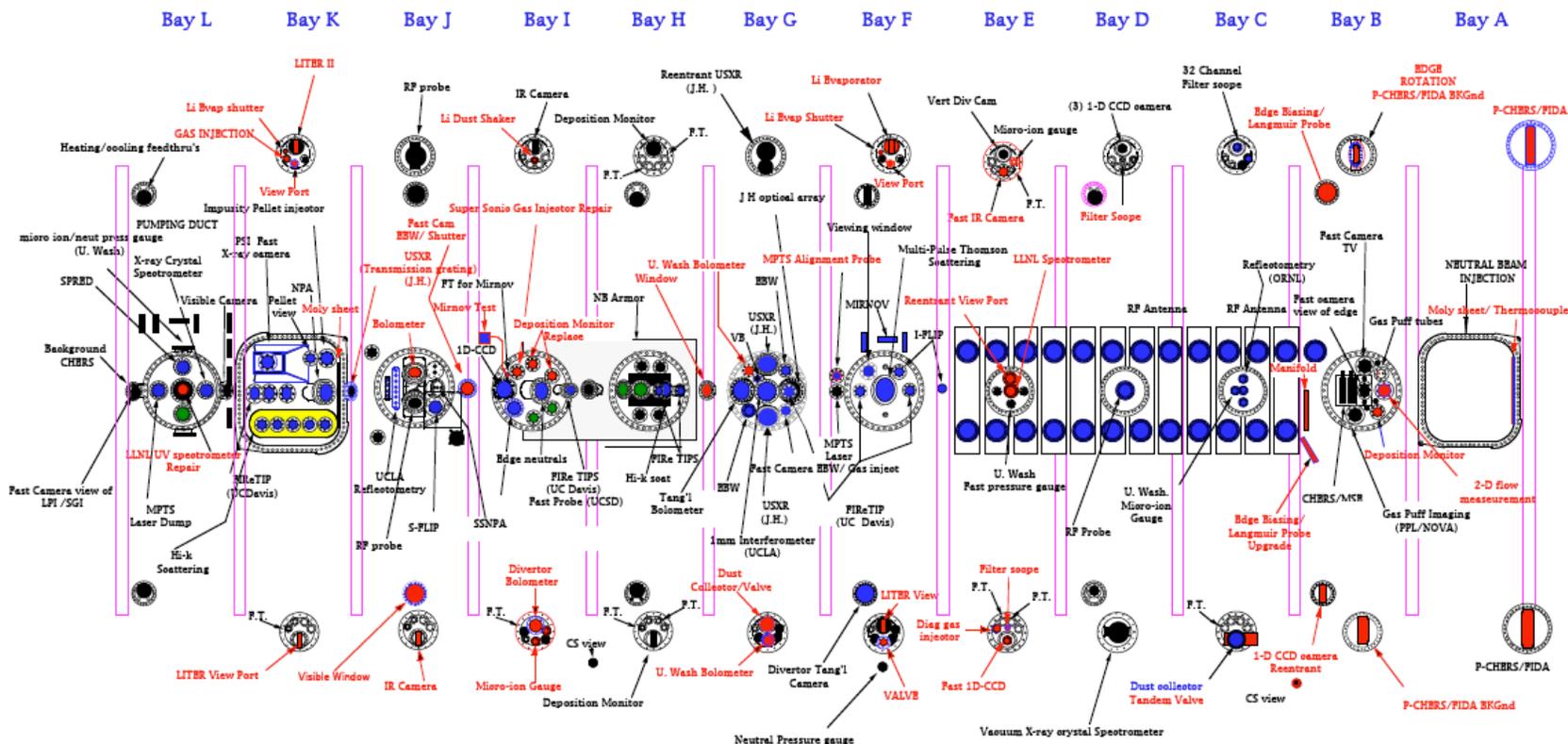
• Present 2D magnetic sensors at Bay H  
Define Start of Toroidal Orientation



# LLD-1 Toroidal Orientation Relative to Existing Diagnostic Port Allocations



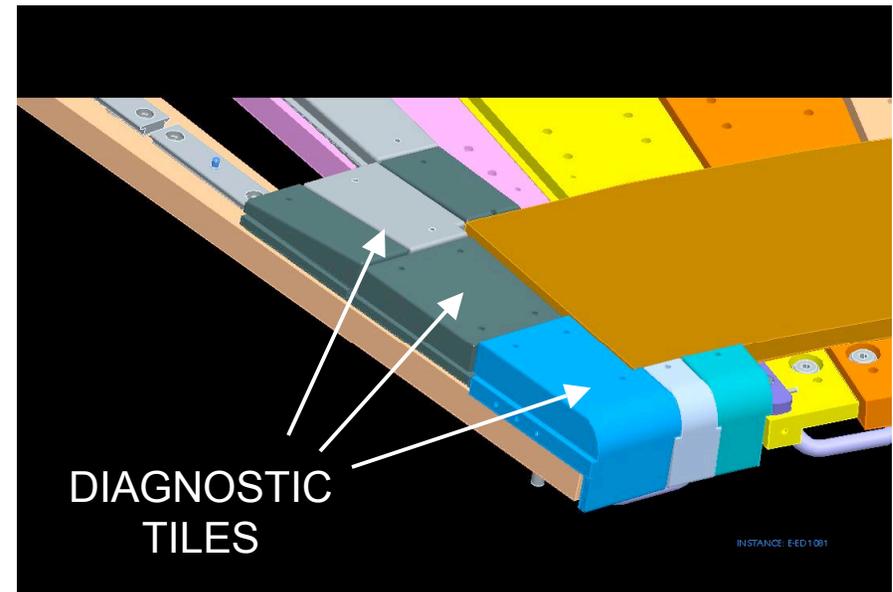
## N S T X LLD Diagnostic 2008 Port Assignments



# LLD-1 Segment Gap Diagnostic Tiles Have Sensors for Control and Characterization

## Listed CCW starting at Bay H

- 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
  - 120 Langmuir Probes (40 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)



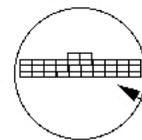
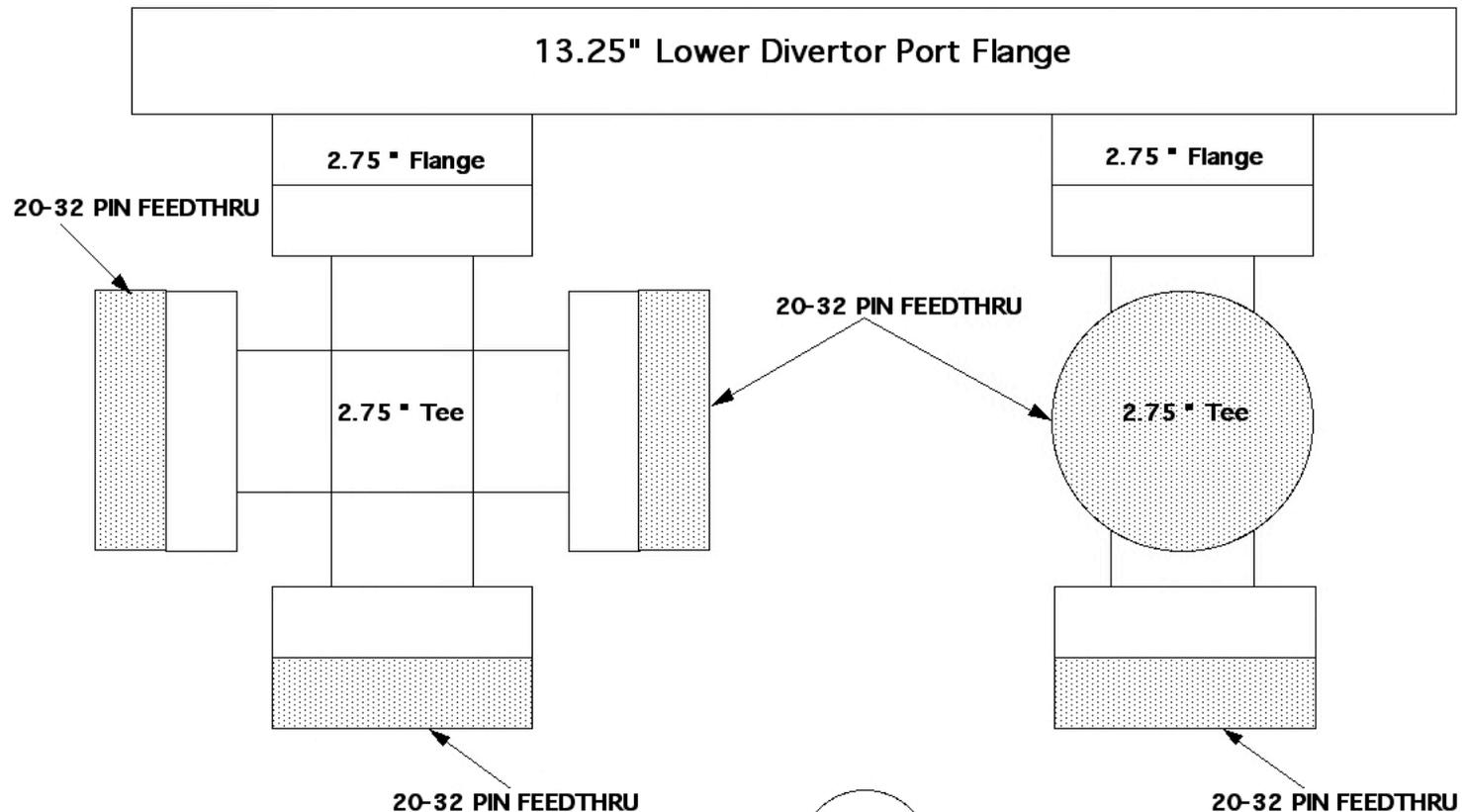
- LLD segment gap Diagnostic Tiles are double width

- *The signal wires will exit the vessel via feedthru assemblies on the 2-3/4 inch lower divertor ports*

# Existing 2-3/4 Inch CF With Tees Provide Sufficient Electrical Feedthrough Capability



## EXAMPLE: 2 FEEDTHRU TEES ON A LOWER DIVERTOR FLANGE



EXAMPLE OF 32 TWISTED PAIRS OF NSTX QUALIFIED TC WIRE OF CROSS SECTION 1/8" X 1/16" PER PAIR SHOWN AT INPUT TO FEEDTHRU CROSS

# Table 1(pg 1 of 3): LLD Wires, Feedthrus



REV: 14JUL08-A

## NOTES

### 1. Definitions

Heater TC = TC embedded in heater

Cu TC-Htrs = TC embedded in copper next to heater

Cu TC-T&R = 4 equally spaced radial TC, embedded in copper 1/3 distance from each end for monitoring toroidal and radial temperature variation

2. 32 pin connectors were assumed for this study. Other pin connectors may be more efficient

LLD SYSTEM		Number	Wire Pairs	Pwr Wires	TC Wires	ProbeWires	Pins per Feedthru	No. Power Feedthrus	No.Instrum Feedthrus
<b>Section H-E</b>									
	Heaters	12	12	24			32	1	
	Heater TC	12	12		24				
	Cu TC-Htrs	12	12		24				
	Cu TC-T&R	8	8		16				
<b>Gap-E Tiles</b>	BiasElectrode	2				2			
	(Zweben)	5							
	LP					5			
	TC	2	2		4				
<b>Total Pwr</b>				<b>24</b>				<b>1</b>	
<b>Total TC</b>					<b>68</b>				
<b>Total Probe</b>						<b>7</b>			
<b>Total Instrum (TC + probe = 68 + 7 = 75 wires)</b>									<b>3</b>

# Table 1(pg 2 of 3): LLD Wires, Feedthrus



REV: 14JUL08-A

LLD SYSTEM		Number	Wire Pairs	Pwr Wires	TC Wires	ProbeWires	Pins per Feedthru	No. Power Feedthrus	No. Instrum Feedthrus
<b>Section E-B</b>									
	Heaters	12	12	24			32	1	
	Heater TC	12	12		24				
	Cu TC-Htrs	12	12		24				
	Cu TC-T&R	8	8		16				
<b>Gap-B Tiles</b>									
	Langmuir								
	Probe Tile-1	40 sets of 3 rows				120	32		3
	TC	2			4				
<b>Total Pwr</b>									<b>1</b>
<b>Total TC</b>					<b>68</b>				
<b>Total Probe</b>						<b>120</b>			
<b>Total Instrum (TC + probe = 68+120 =188 wires)</b>									<b>6</b>

# Table 1 (pg 3 of 3): LLD Wires, Feedthrus



REV: 14JUL08-A

LLD SYSTEM		Number	Wire Pairs	Pwr Wires	TC Wires	ProbeWires	Pins per Feedthru	No. Power Feedthrus	No. Instrum Feedthrus
<b>Section B-K</b>									
	Heaters	12	12	24			32	1	
	Heater TC	12	12		24				
	Cu TC-Htrs	12	12		24				
	Cu TC-T&R	8	8		16				
<b>Gap-K Tiles</b>									
	BiasedElectr (Zweben)	2				2			
	LP					5			
	TC	2	2		4				
<b>Total Pwr</b>				<b>24</b>				<b>1</b>	
<b>Total TC</b>					<b>68</b>				
<b>Total Probe</b>						<b>5</b>			
<b>Total Instrum (TC + probe = 68+ 7 = 75 wires)</b>									<b>3</b>

<b>Section K-H</b>									
	Heaters	12	12	24			32	1	
	Heater TC	12	12		24				
	Cu TC-Htrs	12	12		24				
	Cu TC-T&R	8	8		16				
<b>Gap-H Tiles</b>									
	2D magnetic	5	installed	installed			installed		0
	TC	2	2		4				
<b>Total Pwr</b>				<b>24</b>				<b>1</b>	
<b>Total TC</b>					<b>68</b>				
<b>Total Probe</b>						<b>0</b>			
<b>Total Instrum (TC = 68 wires)</b>									<b>2</b>

# Preliminary Feedthru, Connectorization and Cable Costs



LLD Section	TOTAL WIRES	Power Feedthrus	Instrument Feedthrus	Cables
H-E + Gap E	75	1	3	4
E-B + Gap B	188	1	6	7
B-K + GAP K	75	1	3	4
K-H + GAP H	68	1	2	3
<b>TOTALS</b>	<b>406</b>	<b>4</b>	<b>14</b>	<b>18</b>

LOADED FEEDTHRU COST = 18 FEEDTHRUS x \$0.5K x 1.3 = \$11.7K

LOADED VACUUM HARDWARE = 2 VACUUM CROSSES PER SEGMENT = 8 CROSSES x \$0.19K x 1.3 = \$2.0K

LOADED CABLE COST = 18 CABLES x \$400 x 1.3 = \$9.4K

LOADED CONNECTOR WIRING COST = (406 CONNECTIONS / 6 CONNECTIONS/hr) = 68 hrs x \$100/HR = \$6.8 K

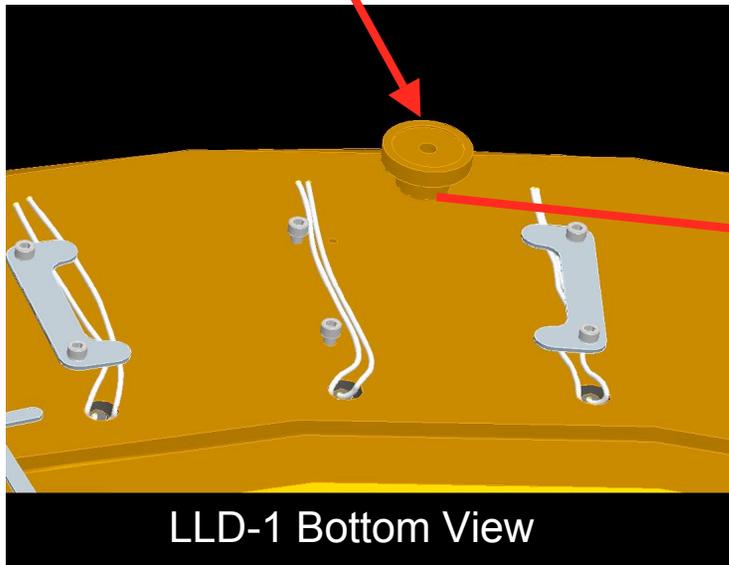
LOADED TOTAL COST = \$11.7K + \$2.0K + 9.4K + 6.8K = \$29.9K

*Review of Individual  
LLD-1 Inter Segment  
Graphite Diagnostics Tile  
Sensors*

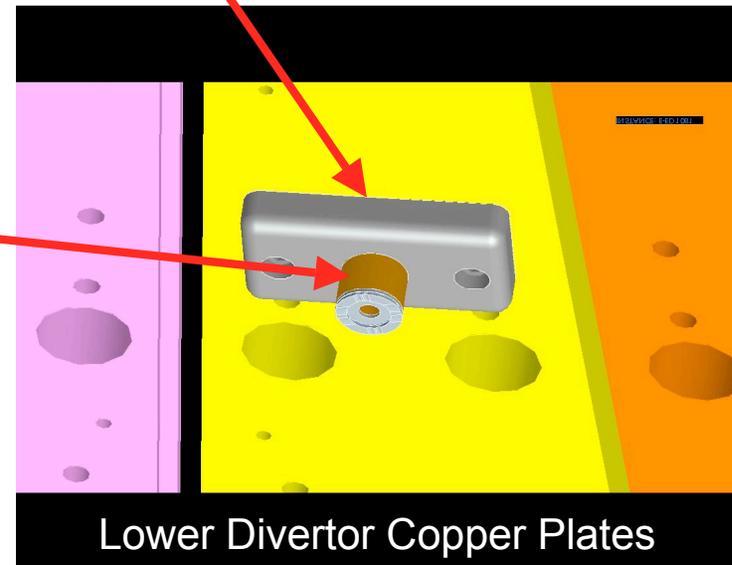
## Each LLD-1 Segment Single Point Ground Will Have Rogowski Halo Current Sensor



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



- Clamp fastens Grounding Post to divertor copper plate



- Grounding Post and Clamp dimensions can be adjusted to accommodate Rogowski Halo Current sensor

S. Gerhardt, L. Guttadora, R. Ellis

# *The Existing 2D Magnetic Sensors at Bay H Will Be Preserved*

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- The 5 present 2D magnetic Sensors at Bay H Lower Divertor are used for control and analysis.
- It is desirable to keep these sensors.
- The Design Plan:
  - the existing cables will be cut at the tiles.
  - the old tiles with embedded sensors will be removed.
  - new tile with fresh identical sensors will be connected to the existing cabling and reinstalled.
  - all external wiring and cabling will remain unchanged.
  - the standard calibration procedures can be applied to the identical replacement sensors.

## I. Physics Requirements

- Need sufficient radial resolution over heat-flux profile width at strike point ( $\sim 10$  cm)
- Probes should straddle LLD radially so as to provide both Li and Carbon data
- Desire high temporal resolution in order to measure transient edge events (ELMs)

## II. Design Requirements

- UIUC will provide signal conditioning and data acquisition electronics for triple probes
- Probes in each triple set should be at same radial location in order to avoid effects of gradients in edge parameters

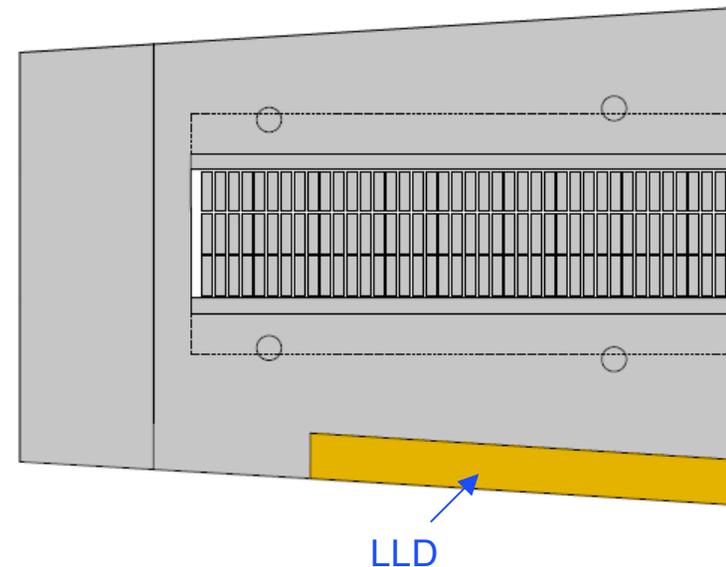
# Tile Langmuir Probe Array - Detail

Tile is ~13 cm long radially,  
spanning 7° toroidally

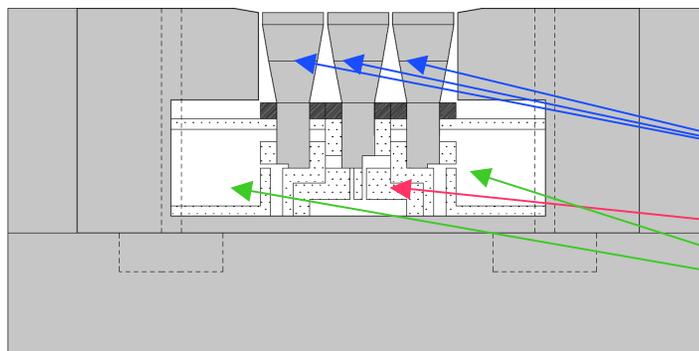
Probes cover ~10 cm and are  
spaced 0.5mm apart

Probe heads are 2.5x7mm  
rectangles

## Tile top view



## Cut-away view from inboard



Probes will be mounted in  
macor cassettes and wires run  
out through side channels

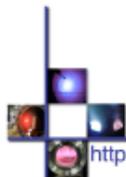
← Inboard

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# LLD and SOL Interactions on NSTX Final Design Review Slides

M. A. Jaworski and D. N. Ruzic  
University of Illinois at Urbana-Champaign

July 16, 2008



Center for Plasma Material Interactions

<http://starfire.ne.uiuc.edu>

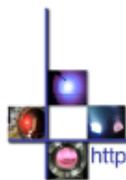
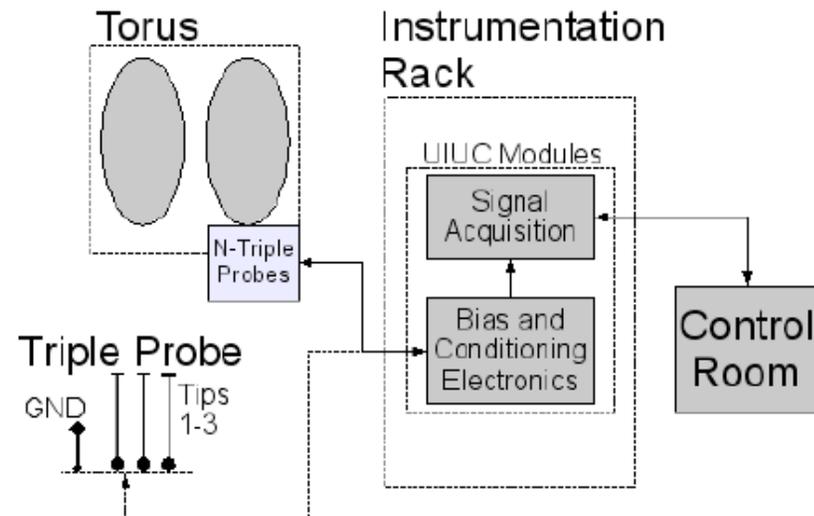
UIUC-NSTX Collaboration Final Design Review July 16, 2008



ILLINOIS  
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

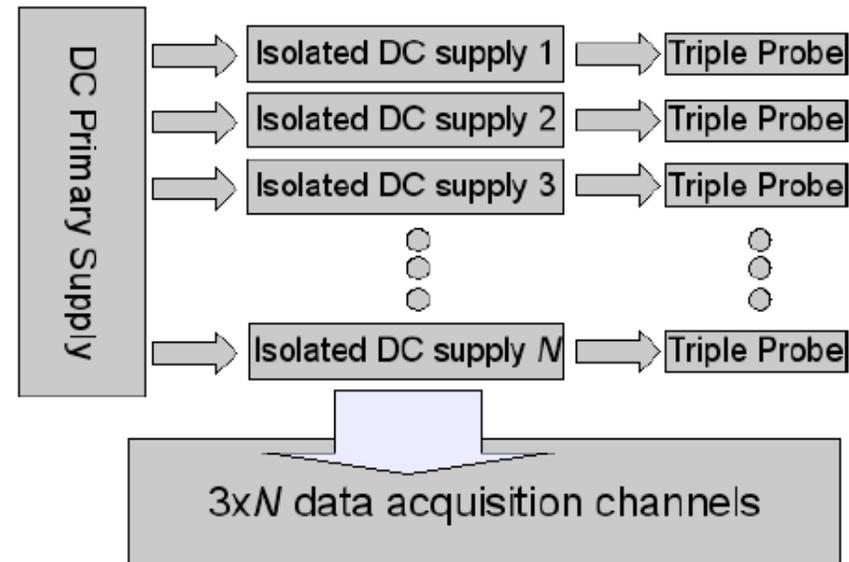
# Overview of UIUC Contribution

- UIUC provides electronics for triple probe system
  - Bias power supply and electronics
  - Signal conditioning and data acquisition
  - Control room operator and analyst
- Triple probe system designed for extendability
  - Each probe consists of 3 tips + GND connection
  - System designed on a “per probe” basis allowing easy addition to electronics packages



# Modular Electronics

- Primary DC source provides “bus” power
- Isolated DC supplies for each TLP
  - Flyback converter topology
  - Independently regulated
  - Independent arc protection and shut-down
  - Independent signal conditioning
  - Straight-forward extension to additional TLPs - “plug in” more modules
  - Testing to occur at UIUC



- Acquisition for  $N=10$  probes initially planned
  - 125kHz bandwidth limit
  - 16-bit resolution
    - $10^{13} \text{ cm}^{-3}$  @ 100eV limit on  $I_{\text{sat}}$
    - 1% of  $10^{11} \text{ cm}^{-3}$  @ 10eV
    - Initial estimates: adjustable if needed



# Diagnostic Tile and LLD-1 Thermocouples



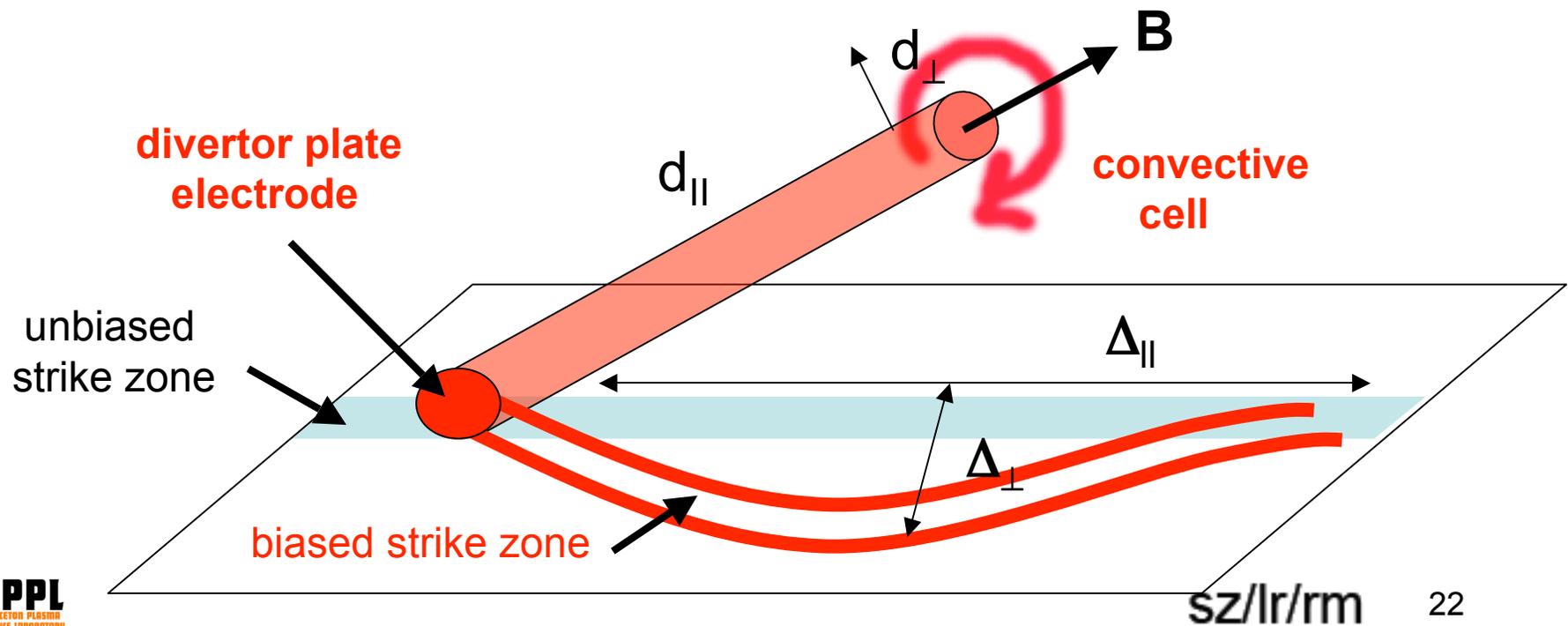
- The inter segment graphite Diagnostic Tile TCs will be installed using proven NSTX graphite armor design
  - TC inserted into well in graphite and potted *in situ* with graphite ceramic cement.
- The LLD-1 TCs will be installed using proven NSTX NBI calorimeter and armor designs
  - coated with high temperature, silver-based conductive epoxy, inserted into 1/16 inch ID hole in copper, and secured by a ping.
  - or TC clad in threaded 304-SS sheath screwed into tapped hole.

R. Ellis, M. Cropper

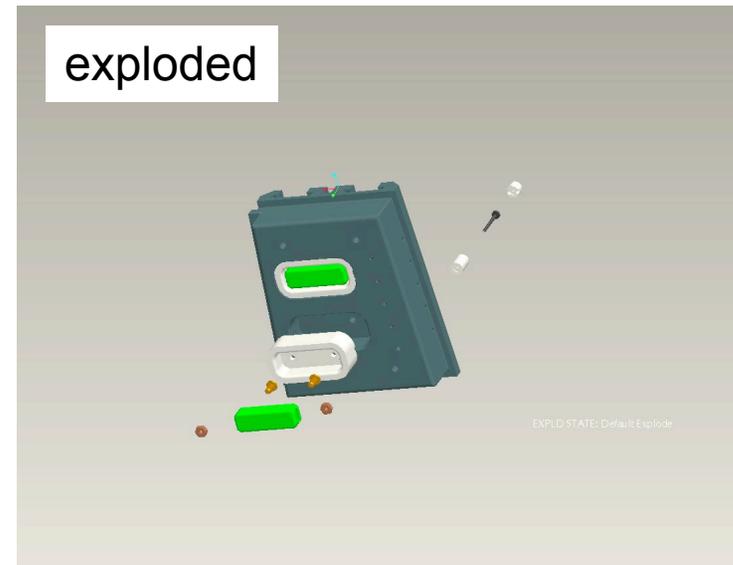
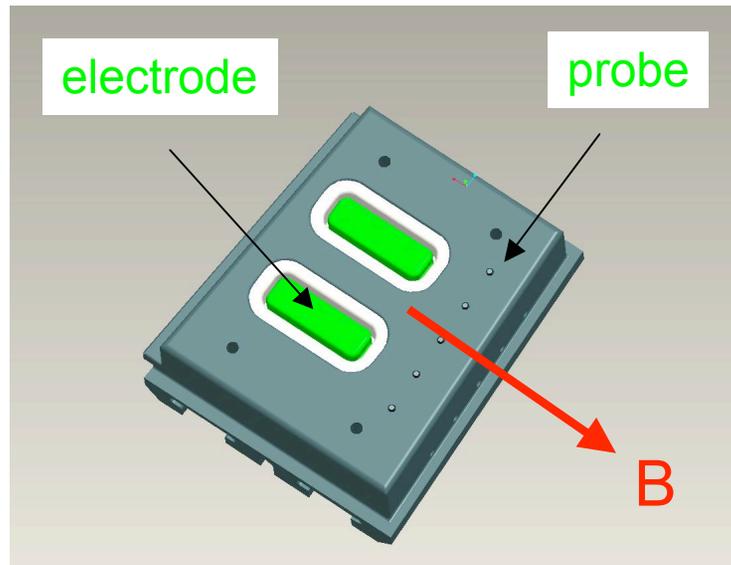
## 2 Diagnostic Tiles 180° apart with Biased Electrodes Enable Unique Measurements During LLD



- Goals:
- test Ryutov/Cohen idea for divertor plate SOL control
  - measure penetration of electric field  $\parallel$  and  $\perp$  to  $B$  using cameras and local Langmuir probes
  - check toroidal angle dependence of SOL width



## 2 Diagnostic Tiles 180° Apart, Each with Two Biased Electrodes and 5 Langmuir Probes

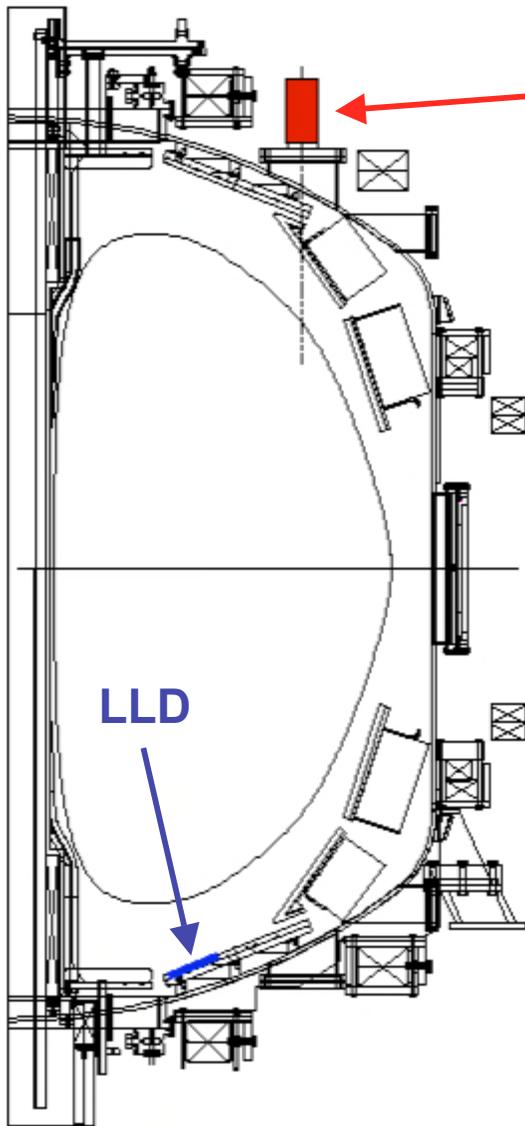


- Graphite electrodes (green): 5 cm x 1 cm, one pair  $\parallel$  and one pair  $\perp$  B
- Langmuir probes: 5 single probes, 1/16" diameter, radially arrayed
- External bias and probe drive/digitizers use existing BEaP hardware

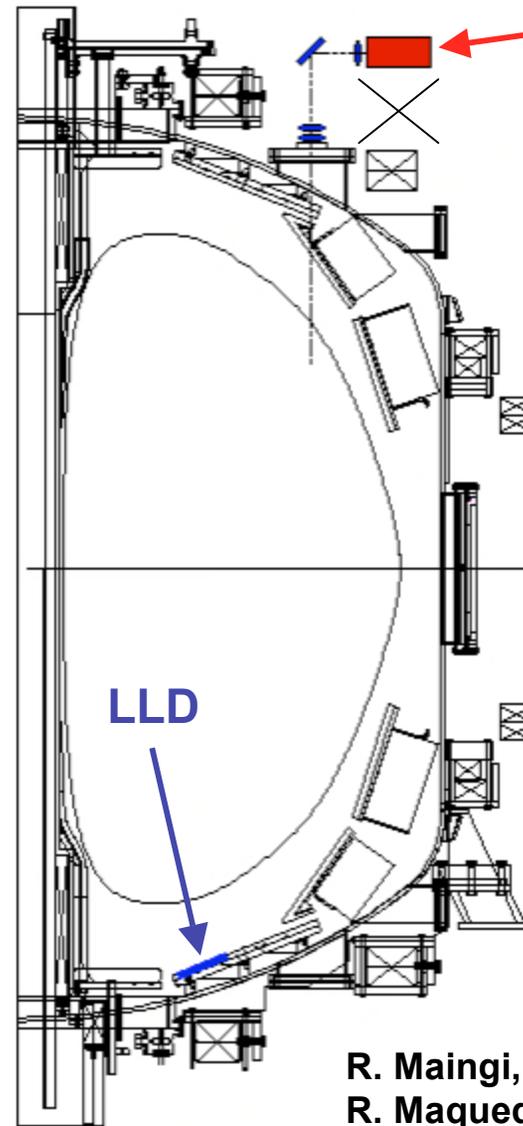
# *External Diagnostics for LLD-1 Characterization*

- **IR Cameras**
  - **Fast IR Camera (downward FOV)**
  - **2 Slow IR Cameras (upward and downward FOV)**
- **Lyman- $\alpha$  Diode Array**

## 2 IR Cameras Will Monitor LLD-1 Operation (Slow) and Characterize ELM Interactions (Fast)



- Present, upper vertically mounted, magnetically shielded, SLOW IR Camera with 12-15° toroidal FOV



- New, horizontally operating, FAST, IR Camera mounted above VV interferences, and viewing through ZnSe periscope with 12-15° FOV

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

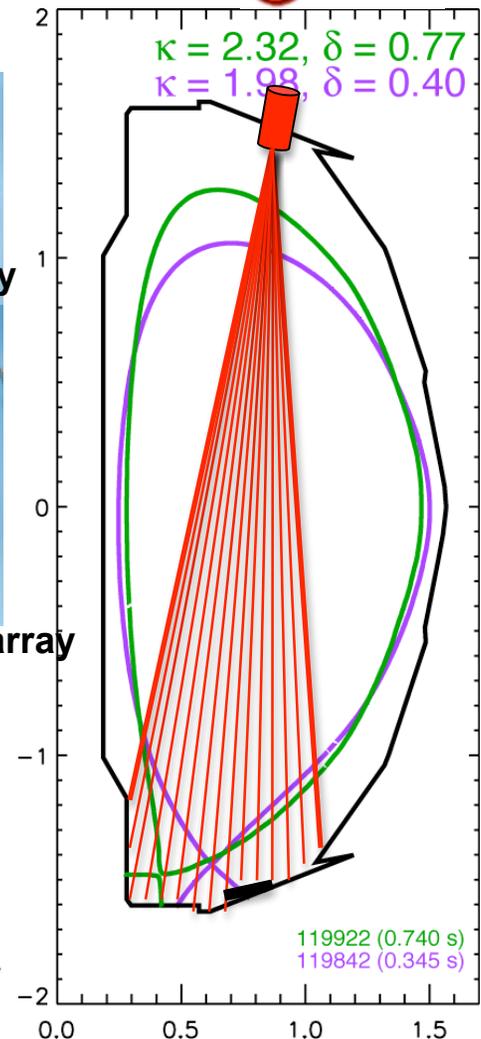
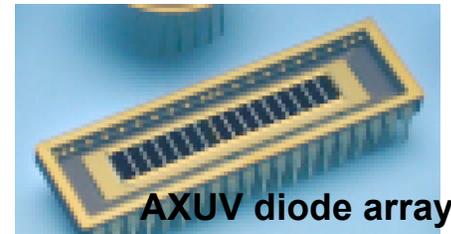
# Lyman- $\alpha$ arrays to be used for recycling rate measurements from highly reflective LLD

Mirror-like lithium surface will complicate interpretation of visible (400-750 nm) spectroscopic diagnostics

AXUV diode arrays with bandpass filters measure Ly- $\alpha$   $n=1-2$  H/D transition at 121.6 nm, where reflections are negligible

16-20 channel diagnostic can be assembled from off the shelf components for 10 K, plus 10-15 K for DAQ system

One array will be fielded in FY09 at Bay G upper divertor port



# Cost and Time



SYSTEM	LOADED M&S \$K	TECH Mhrs	LOADED TECH \$K	ENG Mhrs	LOADED ENG \$K
LLD FEEDTHRU, CABLES CONNECTORIZATION	23.10	68	6.8		
ROGOWSKI (4)	1.00	80	8		
2D MAGNETIC SENSORS		40	4		
LP PROBES	0.50	80	6		
THERMOCOUPLES	0.50	40	4		
BIASED ELECTRODES	0.50	40	4		
IR CAMERA PERISCOPE	3.00	40	4	60	10.8
Lyman- $\alpha$ ARRAY	32.50	40	4	40	1.8
CABLE ENGINEERING				160	28.8
DAQ ENGINEERING				160	28.8
<b>SUB TOTALS</b>	<b>61.10</b>	<b>428</b>	<b>40.8</b>	<b>420</b>	<b>70.2</b>
<b>TOTAL M&amp;S</b>	<b>61.1</b>				
<b>TOTAL LABOR</b>	<b>111</b>				
<b>TOTAL COST</b>	<b>172.1</b>				

# Summary and Conclusions



- ***Onboard Sensors on each LLD 90° Segment:***
  - 12 TC embedded in 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 the inter-segment graphite Diagnostic Tiles:***
  - Bay H: existing 2D magnetic sensor array and 2 TC
  - Bay B: 120 LP array with some UIUC signal conditioners for triple probes
  - Bay E and Bay K: 2 Biased electrodes, 5 LP, 1 TC
  
- ***External Diagnostics:***
  - Bay G: Slow IR Camera, Bay E: Fast IR Camera
  - Bay \_: Lyman- $\alpha$  Diode Array
  
- ***Unresolved Diagnostic needs:***
  - LLD lithium thickness and activation, and its toroidal variation
  - LLD 360° viewing capability