Experimental Studies of the Sheath Power Transmission Factor in the DIII-D Tokamak

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Outline

- Magnetic Fusion Research – DIII-D
- DIII-D Divertor Diagnostics
  - Langmuir Probe Array
  - DiMES Probe
  - Calorimeter
  - Infrared Camera
- Computing the Sheath Power Transmission Factor
- Discrepancy between the measured and theoretical values of the SPTF
- Plans for the Future

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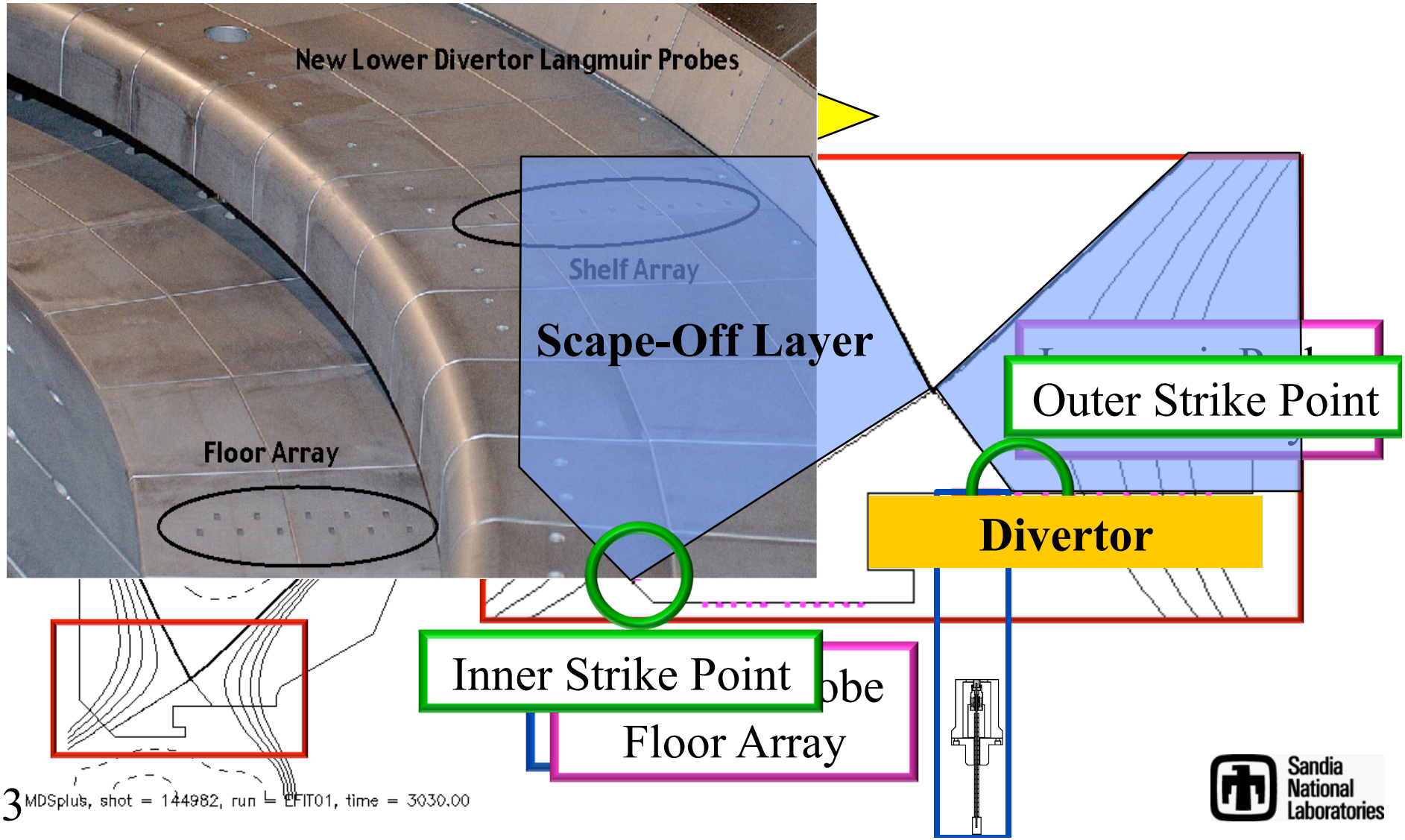
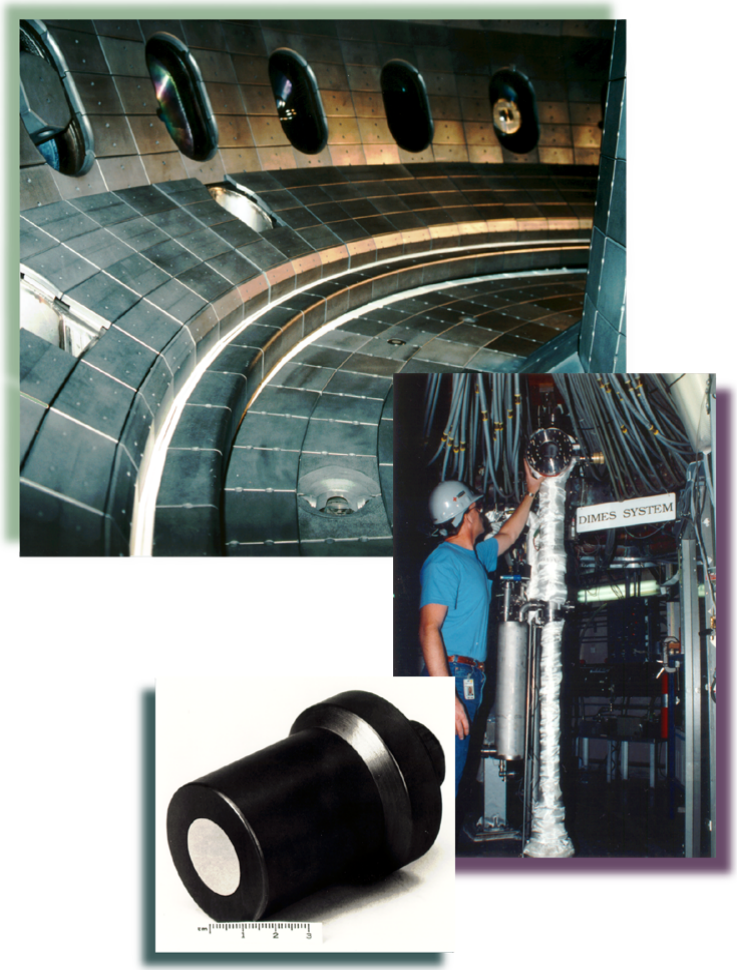
Cross-section of DIII-D Tokamak



Divertor Materials Evaluation System (DiMES)

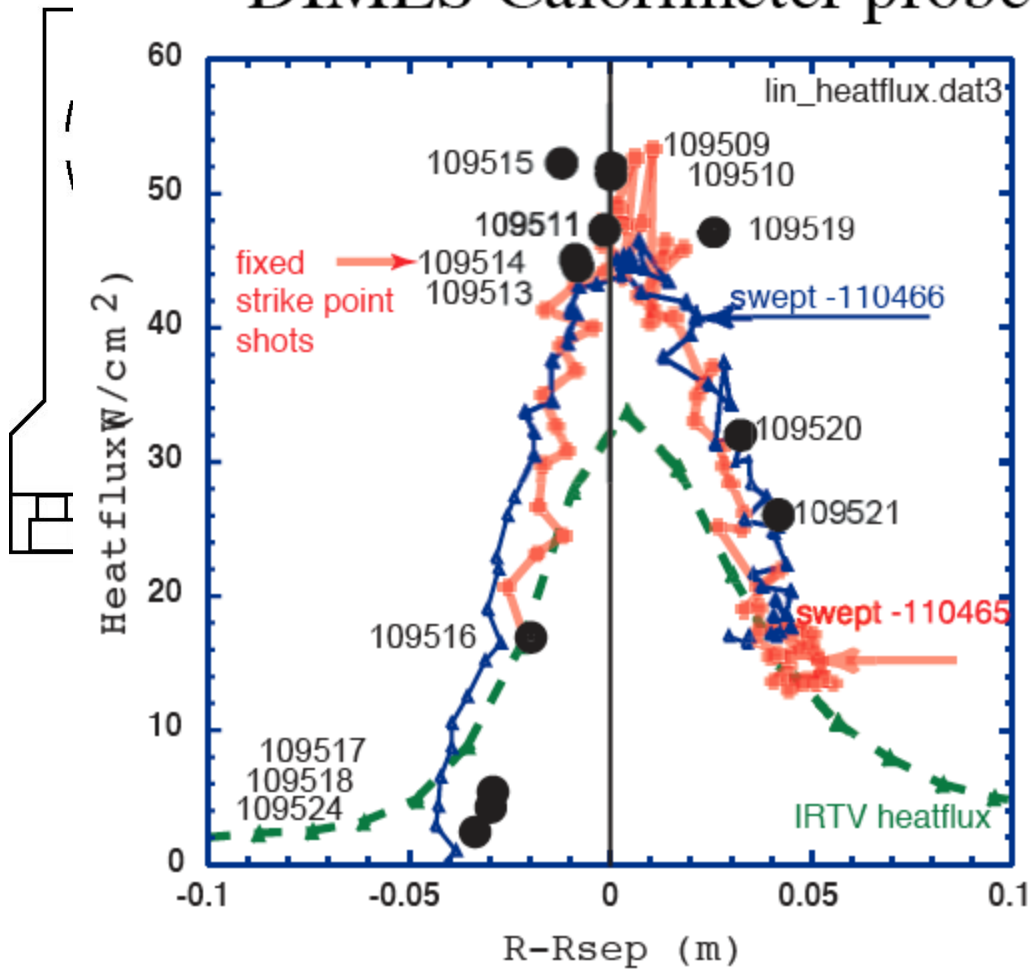
- DiMES head is retractable and is equipped with its own gate valve and pump
- Different DiMES heads can be inserted and removed without disturbing the rest of the vacuum
- Various DiMES heads have been designed and utilized
  - Active Measurements
    - Langmuir Probes
    - Calorimeter Probes
  - Passive Measurements
    - Materials Exposure Studies



Calorimeter Probe installed in DiMES head by Jon Watkins of SNL

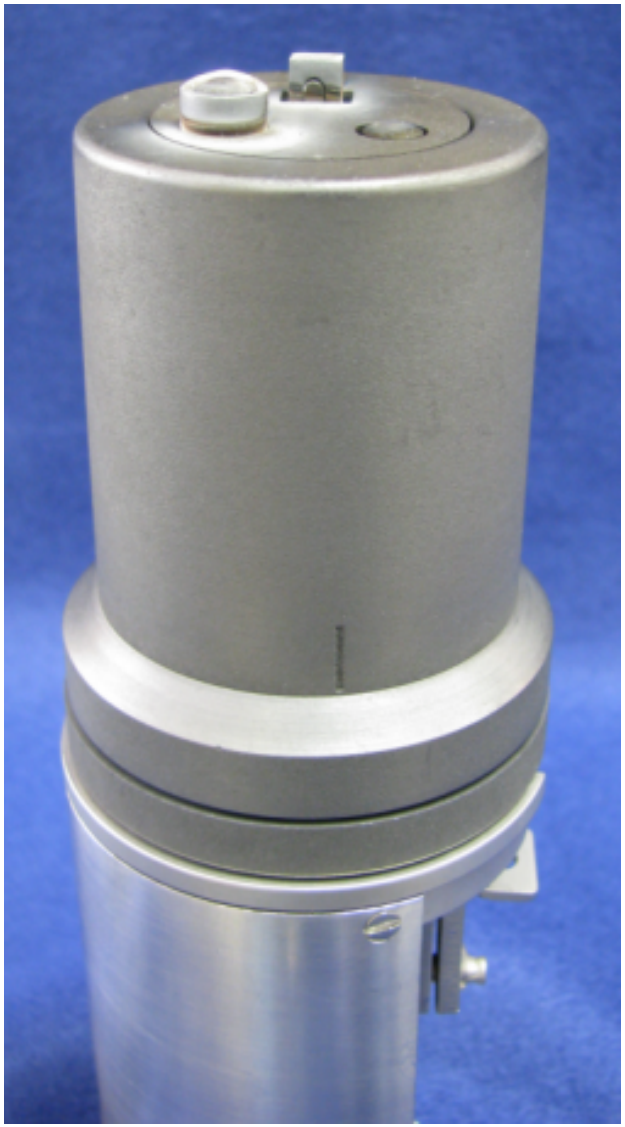
- Calorimeter probe used to collect heat flux measurements
- Compared against measurements of Infrared camera
  - IR camera field of view capable of sweeping across entire floor
  - Calorimeter measured higher heat flux than IR camera
  - IR camera measurements' spatial resolution can often be too course, which potentially leaves out peaks in the heat flux resulting in a lower heat flux profile than actual

Heat Flux Profiles using DIMES Calorimeter probe



DiMES Langmuir Probe Studies

- Applied voltage on the LP is varied sinusoidally and the collected current is measured to provide:
  - Electron Temperature (T_e)
  - Plasma Floating Potential (V_f)
  - Plasma Density (n_p)
- DiMES head is composed of graphite, ~5 cm outer diameter
- Elevated Dome and Planar Probes utilize BN shielding to control exposed area
- Each probe has equal collection area (0.04 cm^2)
- Each probe is equally spaced around a 0.95 cm radius circle to avoid shadowing of one probe on another



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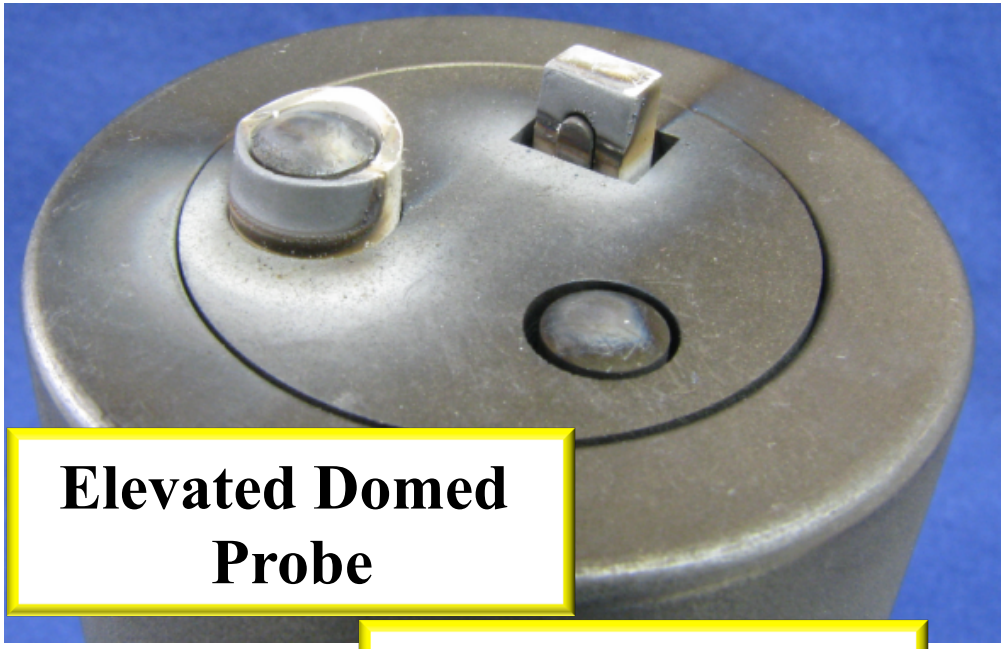
DiMES Langmuir Probe Studies

- Flush Mounted Domed Probe is designed to be similar to other probes in the LP array
- Elevated Domed Probe height is 0.5 cm, which is above the magnetic sheath height (~0.14 cm)
  - Elevated above magnetic sheath in order to determine extent that flux of cold ions from collisional effects in the sheath affect the measurements on the probe
- Planar Probe height is 0.22 cm, intended to be mainly within the sheath
  - Planar face is oriented normal to the magnetic field to mitigate influence of cross field currents reaching the probe
- The three-probe DiMES head can be used to determine the reliability of measurements on the standard domed probes in the rest of the LP network by isolating interfering plasma characteristics for separate study



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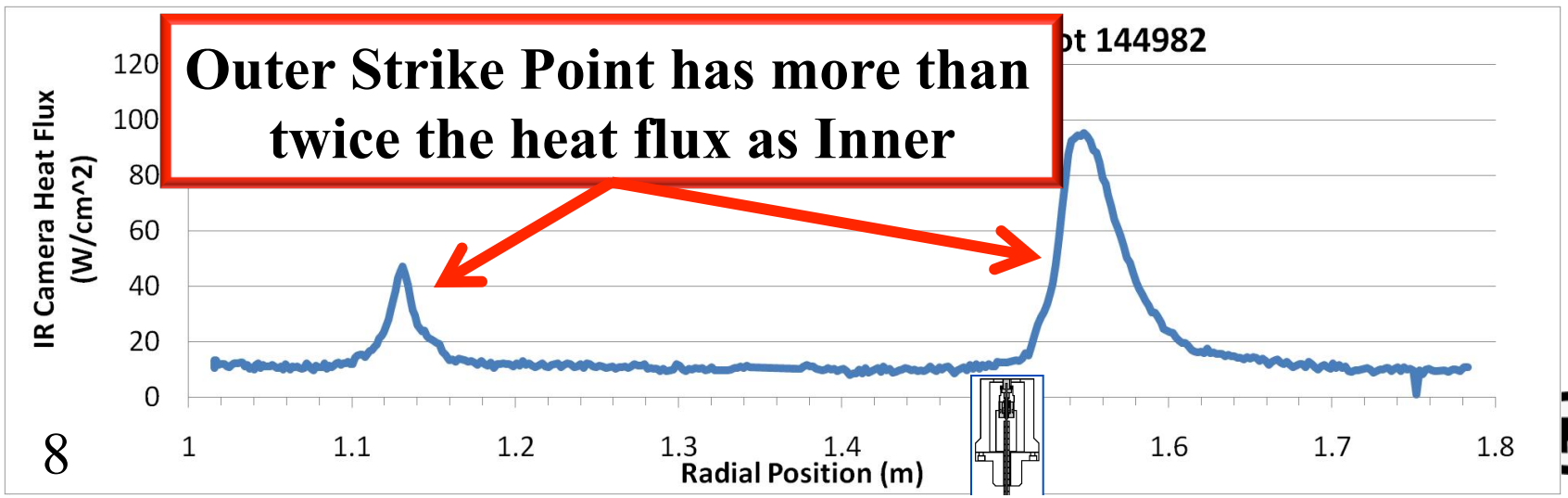
Sheath and the Sheath Power Transmission Factor (SPTF)

- The sheath is a positively charged region between the plasma and vessel walls.
- The SPTF (γ) is needed to properly correlate the particle flux measured by the LP to the heat flux measured by the IR camera

$$\gamma \equiv (Q)/(k \cdot T_e \cdot j^+ / e)$$

- The heat flux (Q) (W/cm^2) is typically measured using the IR Camera
- The electron temperature (kT_e) (eV) and ion saturation current (j+) (A/cm^2) are measured using Langmuir Probes



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Sheath and the Sheath Power Transmission Factor (SPTF)

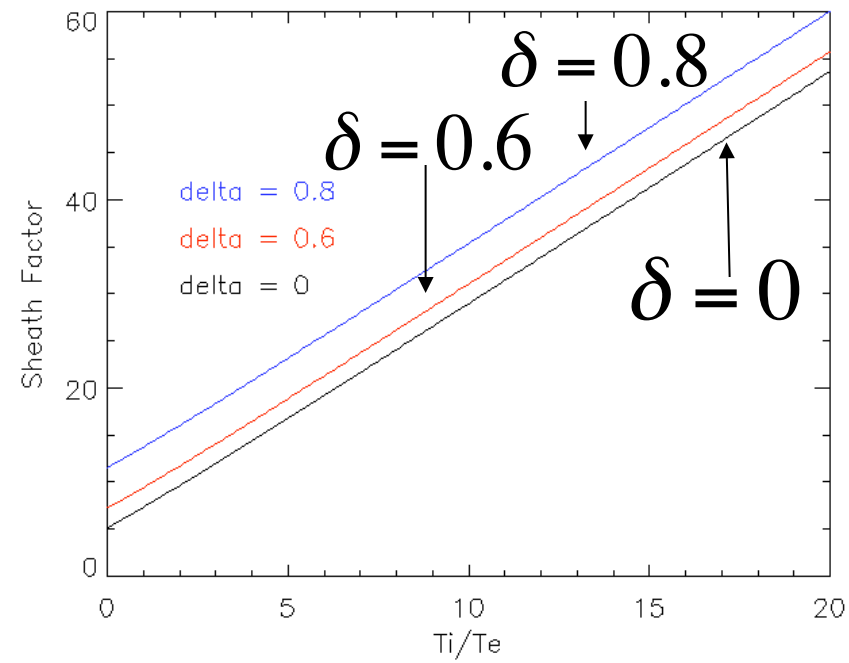
- Theoretical definition of the SPTF:

$$\gamma \approx \frac{2.5 \cdot T_i}{T_e} + \frac{2}{1-\delta_e} - 0.5 \cdot \ln\left[(2\pi \cdot \frac{m_e}{m_i})(1+\frac{T_i}{T_e})(1-\delta_e)^{-2}\right]$$

- For the conditions typically studied, the SPTF should be ~7
- The lowest theoretical value of the SPTF that can be obtained occurs when T_i/T_e and the secondary emission coefficient (δ_e) are both approaching zero

  γ_{min} = 5.18 for Deuterium plasmas

Sheath Factor Profiles



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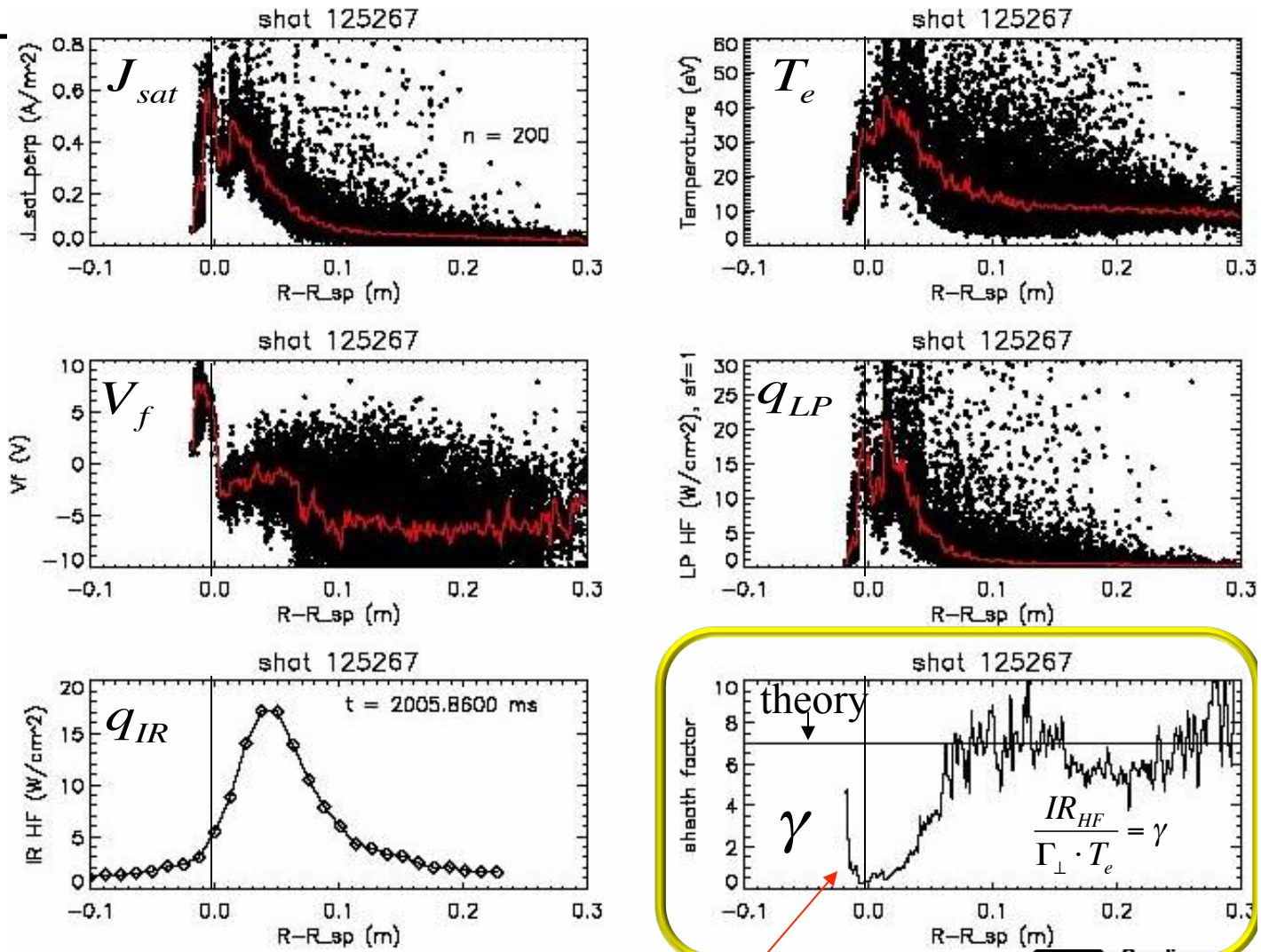
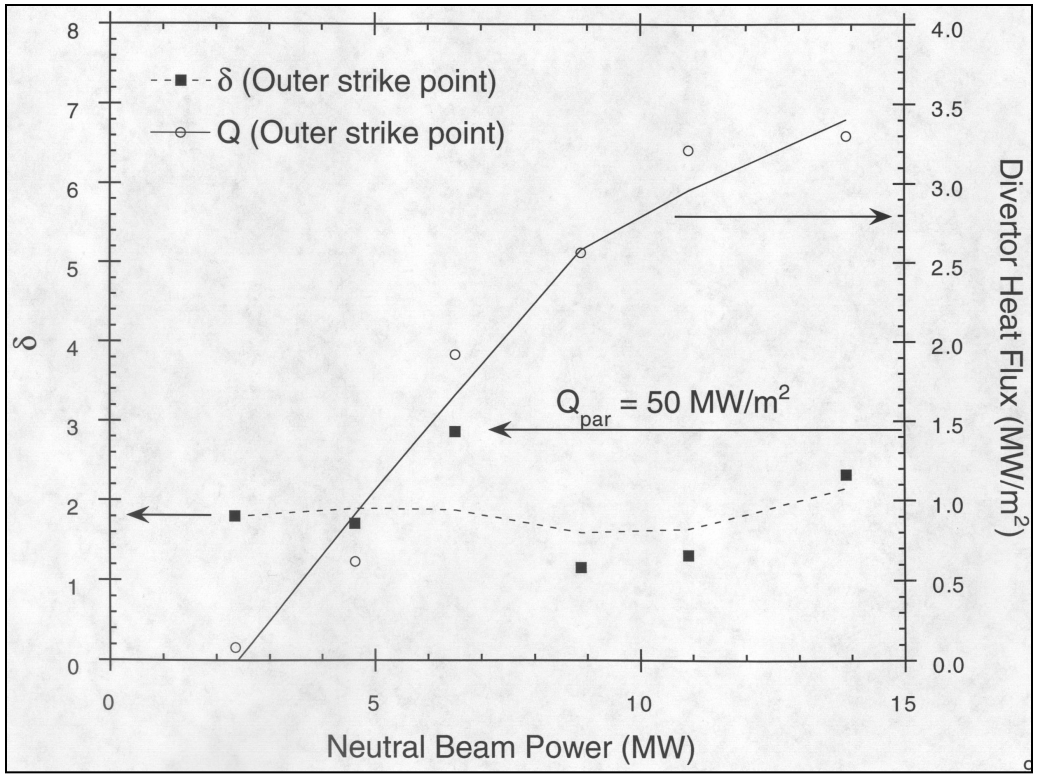
Sheath factor theory has problems near the strike point

- The sheath factor profile is too low at the strike point, typically ~1-2
- Scrape-off layer values of sheath factor agree with theory prediction of ~7.
- New high power pyrolitic graphite Langmuir probes (with lower surface temperature) get the same heat flux answer as before.



Sheath Power Transmission Factor

- SPTF remains roughly constant at the strike point (~1-2) as injected power and divertor heat flux are increased, even for high density plasmas
- γ approaching 1-2 are difficult to understand for divertor plasmas
  - Is the measured **ion flux** larger than expected for the probe A_p?
  - Is interpretation of the probe characteristics not giving $\boldsymbol{T_e}$ correctly?
  - Is the measured **heat flux (IR)** too low (unknown emissivity?)



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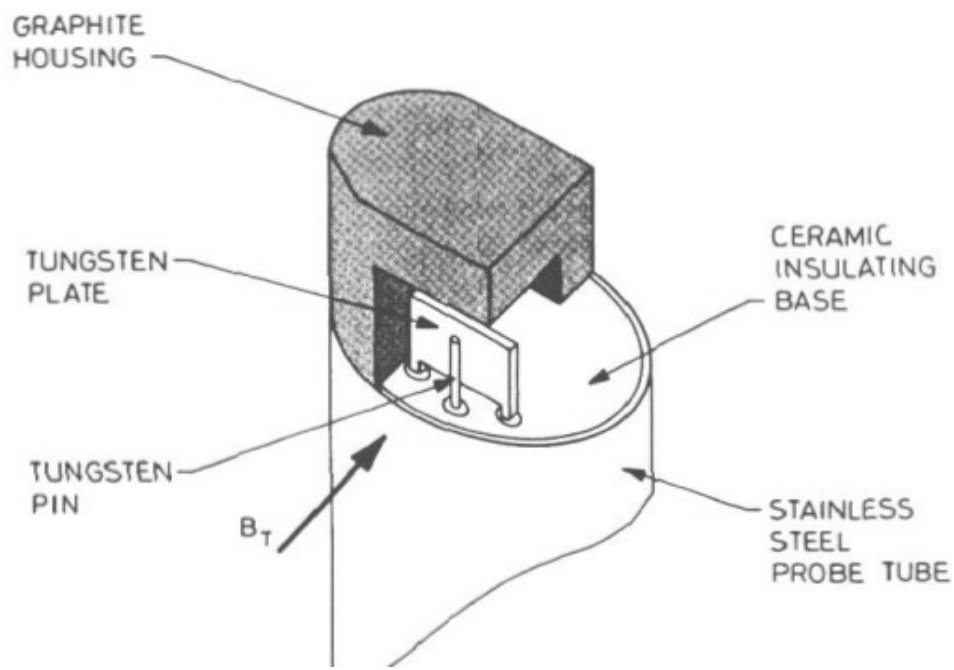
Future Plans – New DiMES Head

- DiMES offers a unique platform on which new probe designs can be implemented during a DIII-D campaign without disrupting the rest of the experiment
- Pin-plate probe design (Stangeby, 1995) is currently being considered to more accurately measure the electron temperature in the presence of a magnetic field
  - Magnetic field makes measurements above the floating potential suspect
  - Unrealistically high values of T_e are obtained due to the magnetic field interfering with electron current at probe
  - Floating pin in front of the principal LP plate allows direct measurement of the plasma potential
  - More of the I-V trace can then be used, allowing for a more accurate calculation of T_e as well as the SPTF



Stangeby, P. C., Plasma Physics and Controlled Fusion, 37, 1337-1347 (1995)

Future Plans – Alternate Methods of Measuring Heat Flux

- Heat flux is currently measured using IR camera
  - IR camera is typically very reliable, but may not able to capture the full heat flux due to relatively course spatial resolution
  - Low measurement of heat flux will result in a low value calculated for the SPTF
- New thermocouple network has been installed below the divertor tiles
  - Combined with thermal conductivity modeling, the TC network can be used to determine heat flux on tiles
- Calorimeter probe head on the DiMES diagnostic has demonstrated higher values of the heat flux than the IR camera
- Heat flux can be measured using the thermocouples or the calorimeter and used in conjunction with the Langmuir measurements to provide independent means of measuring the SPTF in order to determine the reason for low SPTF values

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Questions?

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