Comparison of Langmuir Probe and Thomson scattering measurements in DIII-D

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ABSTRACT

- In this paper we compare measurements of density and electron temperature made by target plate Langmuir probes (LP) and the divertor Thomson scattering (DTS) diagnostics in the DIII-D tokamak divertor. By examining low density, Ohmic, ELM-free discharges, we can use the simple, standard electron thermal conduction model (SETC) to relate the measurements at different but closely spaced locations. For this, essentially sheath-limited, near isothermal regime, we have derived a correction factor of ~0.8 for local LP temperature values based on the SETC model. We have sorted the DTS measurements above the plate onto flux surfaces, calculated the connection length to the plate, and constructed parallel density and temperature profiles for comparisons along the magnetic field lines. Measurements from both diagnostics are consistent with the predictions of this very simple model.

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HIGHLIGHTS

- The DTS and LPs are at different locations (~1 m along B)
  — Need to use a model to compare them
- At low density, the sheath-limited regime exists
  — Use the electron conduction model to relate the two measurements
- At low density, the LP T_e is $\lesssim$20% higher than the local plate T_e
- A mean free path correction predicts this ~20%
- A simple electron conduction model seems to fit the upstream DTS data
  — DTS and LP measurements are consistent

CHARACTER OF THE MEASUREMENTS

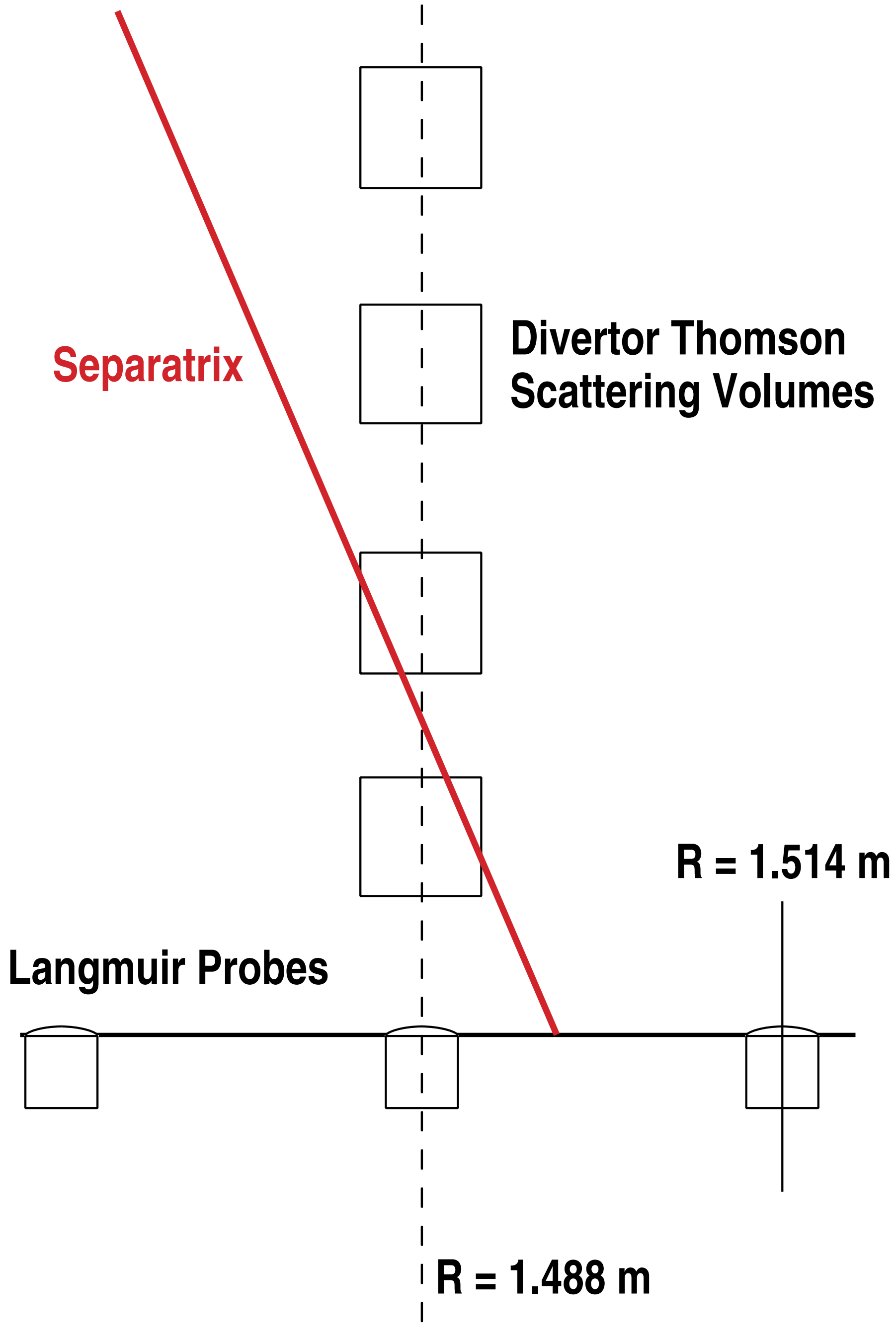
- **Even the closest Thomson measuring location to the target is ~1 m along B. Differences in density and temperature can occur within that distance. The probe T_e measurement samples the higher energy tail of the electron distribution function while the Thomson measurement is of average energy electrons. The e-e mean-free path for tail electrons, λ_{ee}, is an order of magnitude longer than for the average electrons and, thus, it is a less localized measurement than the Thomson. In the presence of a parallel temperature gradient, the probe T_e is somewhat higher than Thomson at the same place.**

DIAGNOSTIC LAYOUT

- The Divertor Thomson Scattering (DTS) diagnostic measures the electron density and temperature vertically above the divertor floor. The boxes shown in the figure below represent the 1 cm^3 scattering volume of the first four DTS channels (0, 1, 2, 3).

- The lower divertor Langmuir probe array intersects the radius of the Thomson at R = 1.488 m. Three of the twenty-eight Langmuir probes are shown in the figure below (3–1, 3–2, 3–3). These graphite probe tips are 6 mm in diameter and protrude 1 mm above the divertor floor.

- The outer divertor leg separatrix is shown below. To the right of this line is the scrape-off layer and to the left is the private flux region.


Separatrix
Divertor Thomson
Scattering Volumes
R = 1.514 m
Langmuir Probes
R = 1.488 m

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HOW CAN WE COMPARE THE MEASUREMENTS?

1. Assume toroidal symmetry
   — Sampling the same field line is too limiting

2. Move the plasma around (slightly, i.e. sweep)
   — Sample the same flux surfaces with both diagnostics
   — Sample several different flux surfaces as well

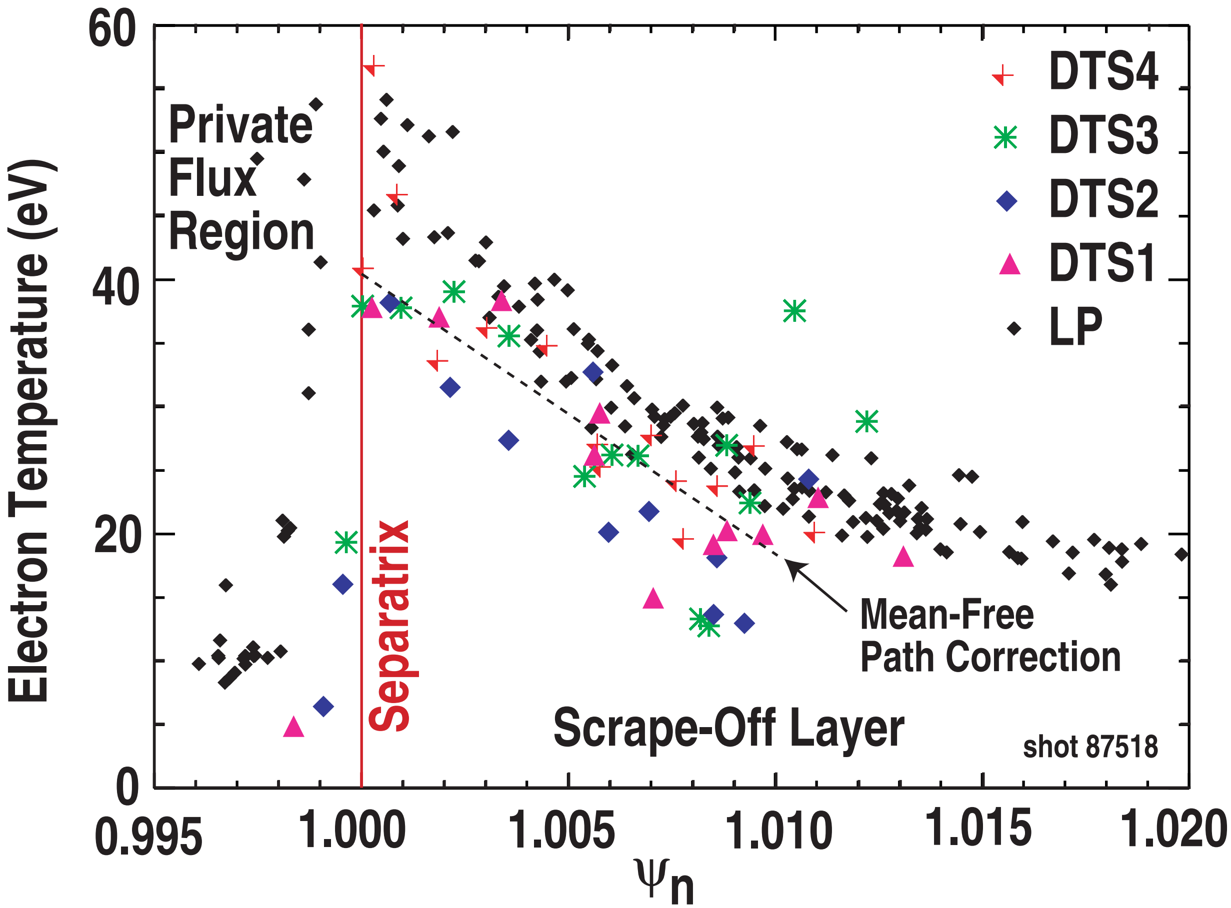
3. A model is needed — in order to relate the measurements made at different locations
   - What is the simplest condition to model?
     — Near-isothermal (the "sheath-limited" regime)
     — This condition can be found at low density

COMPARISON TECHNIQUE

- Combine probe and Thomson measurements from different parts of the scrape-off layer in the divertor outer leg for low density, non-ELMing, Ohmically heated plasma
- Use EFITD6565D to generate an equilibrium grid
- Interpolate the magnetic flux grid on a 10X finer mesh
- Calculate the length along the magnetic field connecting the DTS measurement locations to the target plate
- Sort these measurements by magnetic flux (ψ_n) and $S_{||}$
- Compare density and temperature along the field with the electron thermal conduction model

TEMPERATURES UPSTREAM SEEN BY LP AT LOW DENSITY

- The figure shows the electron temperature profile comparison.
  At this very low density, we expect the local target temperature to be ~80% of the measured value because of averaging over the mean-free-path of the tail electrons along the field line. This is about what is observed here.



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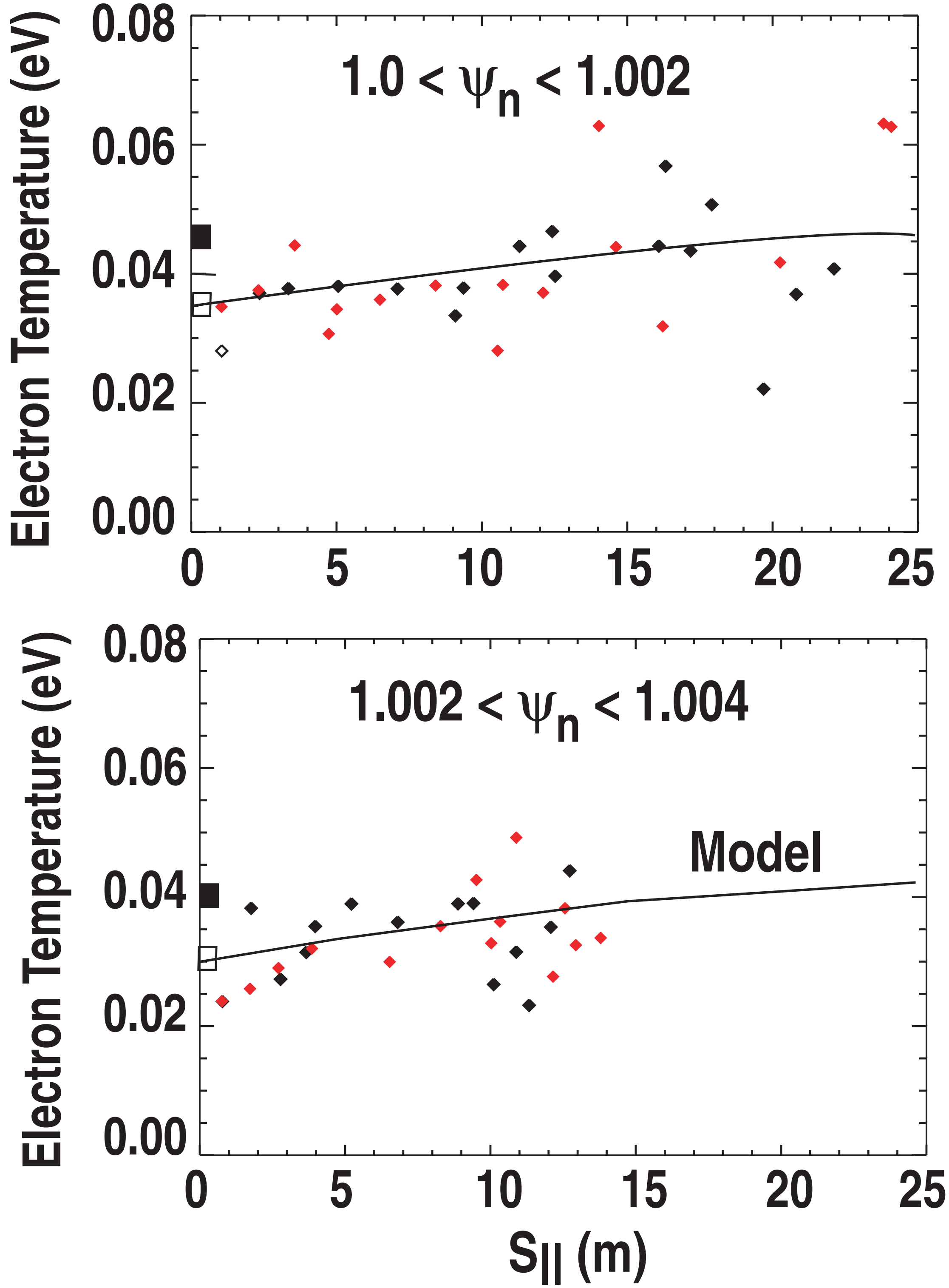
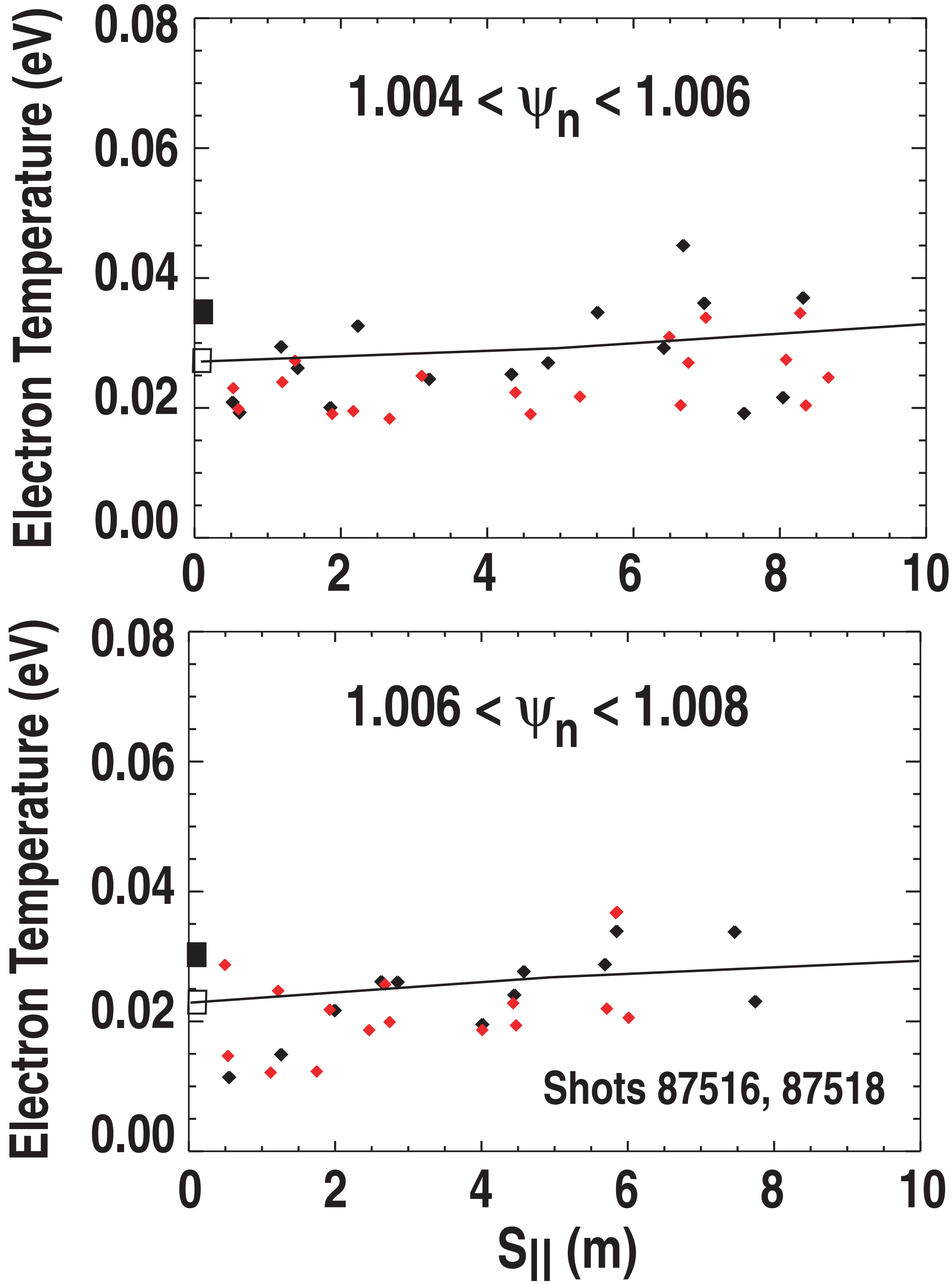
PARALLEL TEMPERATURE RISES SLOWLY AWAY FROM PLATE

- The figures below show the parallel electron temperature profile (along the field) as measured by the DTS (diamonds). The solid boxes at $S_{||} = 0$ are the target plate values measured by the Langmuir probe (LP). The open boxes are the corrected values of $T_e(S_{||} = 0)$ given by the standard electron thermal conduction model (~80% of the measured value). This correction is based on the assumption that the target probe registers the value of T_e given by the $T_e(S_{||})$ profile, calculated by the electron conduction model and evaluated at $S_{||} = \lambda_{ee\text{-}tail}$.

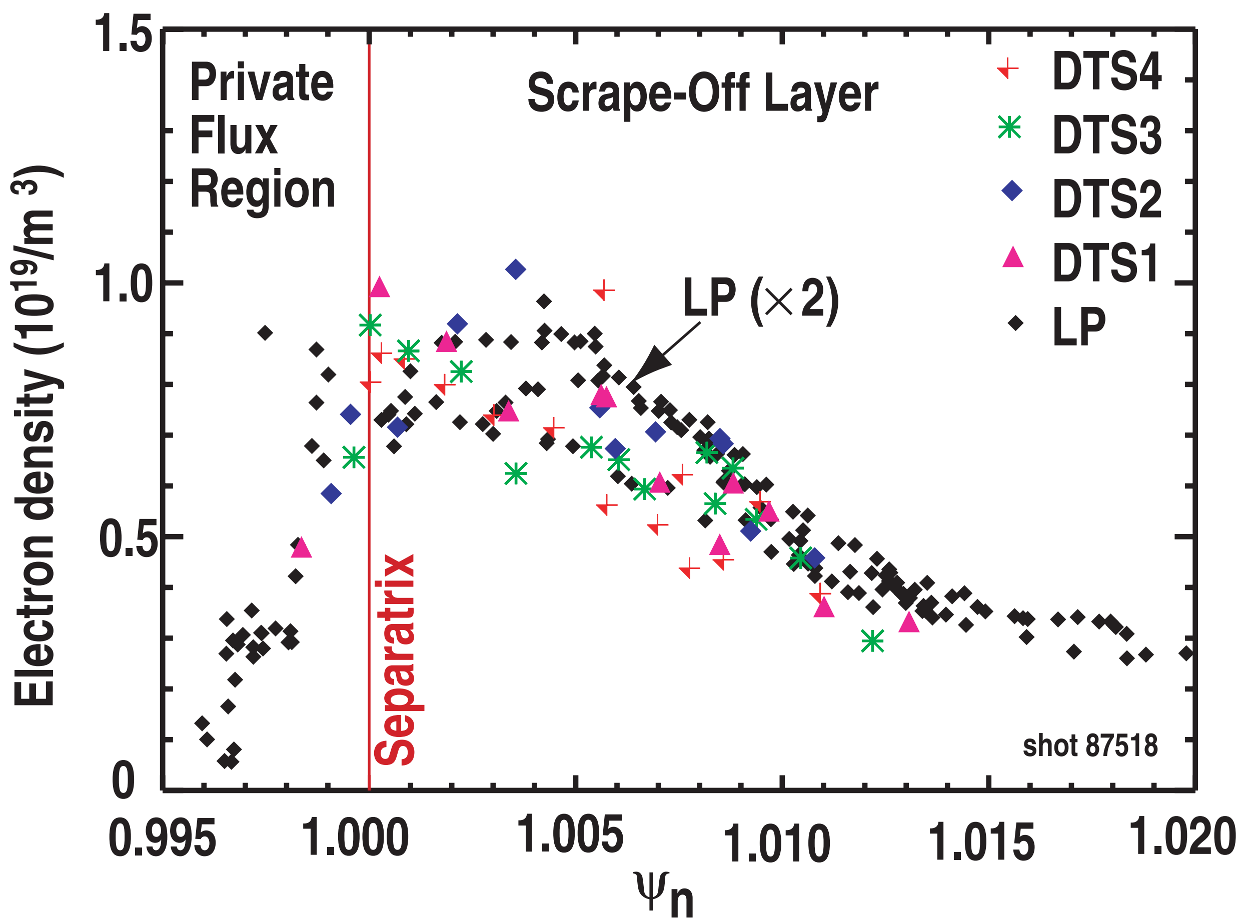


1.0 < ψn < 1.002
Electron Temperature (eV)
0.00
0.02
0.04
0.06
0.08
0
5
10
15
20
25
1.002 < ψn < 1.004
Model
Electron Temperature (eV)
0.00
0.02
0.04
0.06
0.08
0
5
10
15
20
25
S|| (m)


1.004 < ψn < 1.006
1.006 < ψn < 1.008
Electron Temperature (eV)
0.08
0.06
0.04
0.02
0.00
0
2
4
6
8
10
Shots 87516, 87518
S|| (m)

PRE-SHEATH DENSITY TWICE THE TARGET DENSITY

- At the plate, the static pressure drops by a factor of 2 as ions are accelerated to the sound speed. The electron temperature is expected to be ~ constant. Therefore, the density measured before the pre-sheath drop should be twice the target plate density. The measurements roughly follow this basic expectation.



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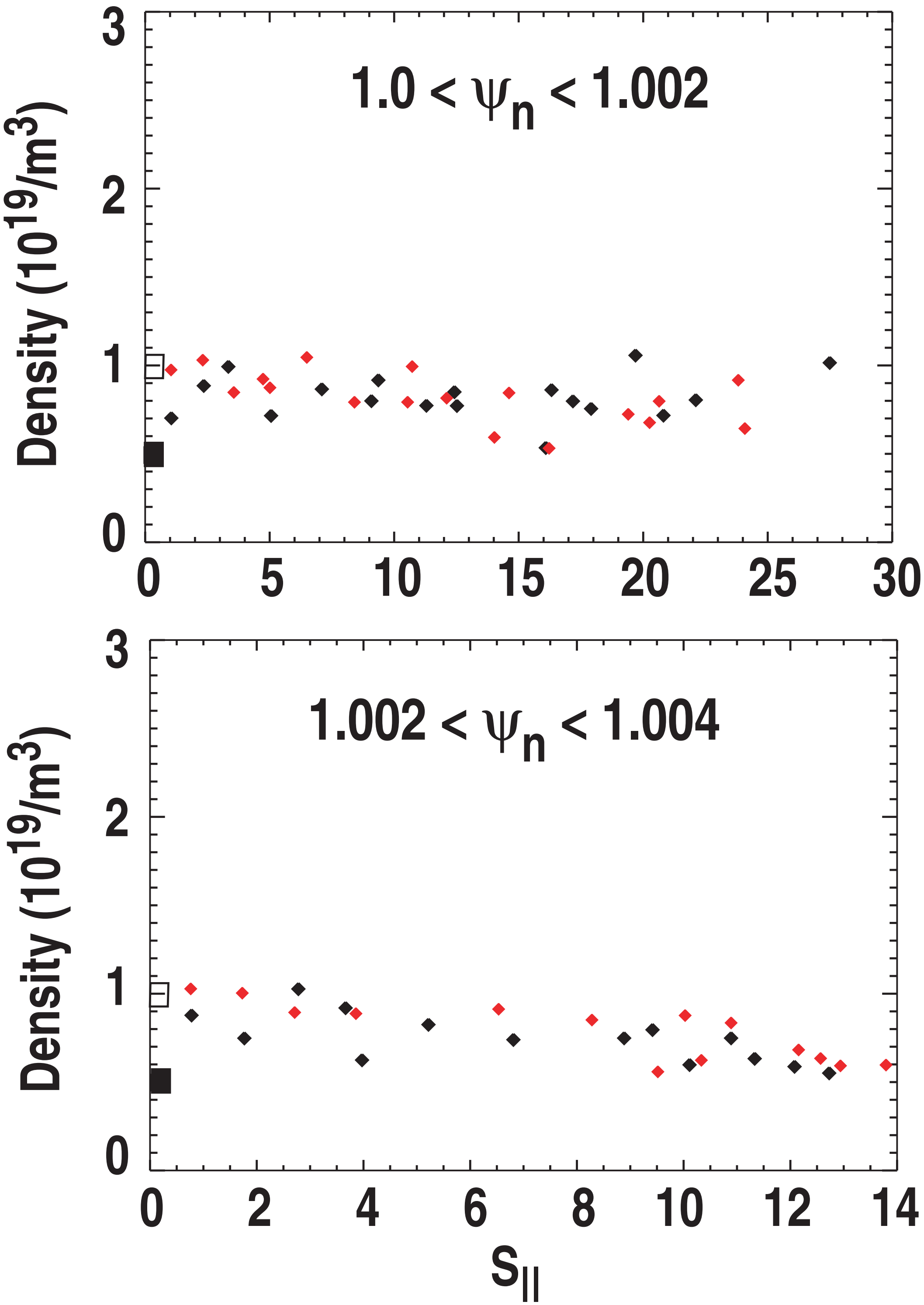
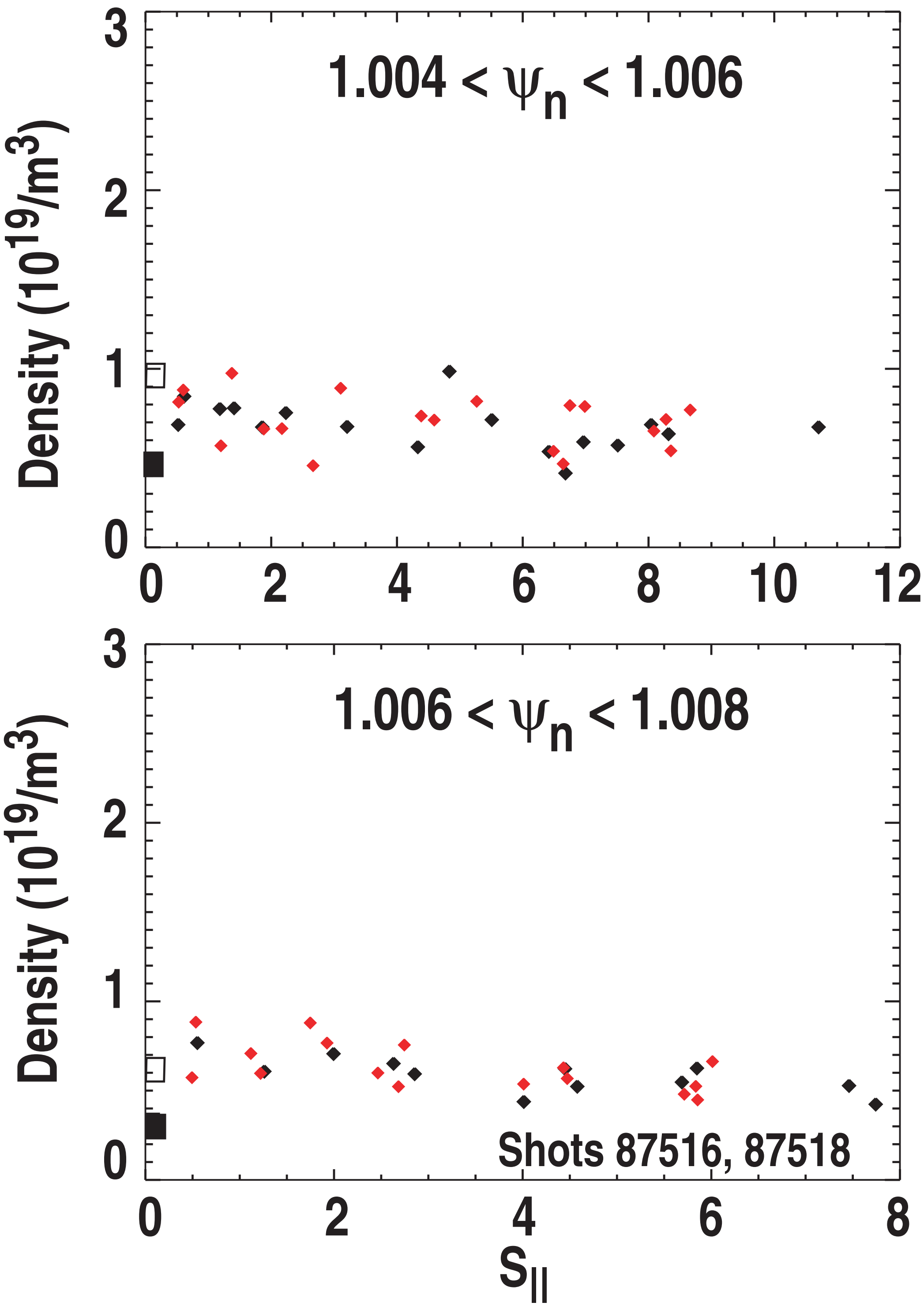
DENSITY ALONG THE FIELD IS FLAT, TWICE THE TARGET VALUE

- The figures below show the parallel density profiles measured by the DTS (diamonds) compared to the target plate densities measured by the Langmuir probe (solid boxes) for four flux "surfaces". The density is almost constant along the field and the target plate value agrees with that expected — i.e. half the upstream value. For comparison, the open boxes in the figures below are twice the target plate LP value. The ionization distance is of the order of 1 m. Simple isothermal plasma modeling predicts that the density drop in front of the target will occur over a distance shorter than the ionization distance. The Thomson measurement locations are not close enough to the target to be able to spatially resolve the density drop.



1.0 < ψn < 1.002
Density (10^19/m^3)
0
1
2
3
0
5
10
15
20
25
30
1.002 < ψn < 1.004
Density (10^19/m^3)
0
1
2
3
0
2
4
6
8
10
12
14
S||



1.004 < ψn < 1.006
1.006 < ψn < 1.008
Density (10^19/m^3)
Density (10^19/m^3)
Shots 87516, 87518
S||

CONCLUSIONS

- We compared measurements at different (but close) locations made by Langmuir probes and the divertor Thomson scattering diagnostic in DIII–D
- The comparisons were done at low density in order to achieve the simplest modeling situation, i.e. near isothermal, “sheath-limited” conditions
- By sorting the measurements into flux surfaces, parallel profiles were obtained which confirm that conditions were near “sheath limited”
- Both diagnostic measurements are consistent with the model within the limits of the statistics and experimental uncertainties for this simple case