OEDGE Analysis of DIII-D Simple As Possible Plasmas that Approach Detachment

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Objectives:

- Assess the consistency and interpretability of the principal divertor diagnostic measurements for three sets of SAPP plasma densities.
- Assess the sensitivity of these diagnostics to variations in the plasma conditions.

Background:

What is the purpose of SAPP?

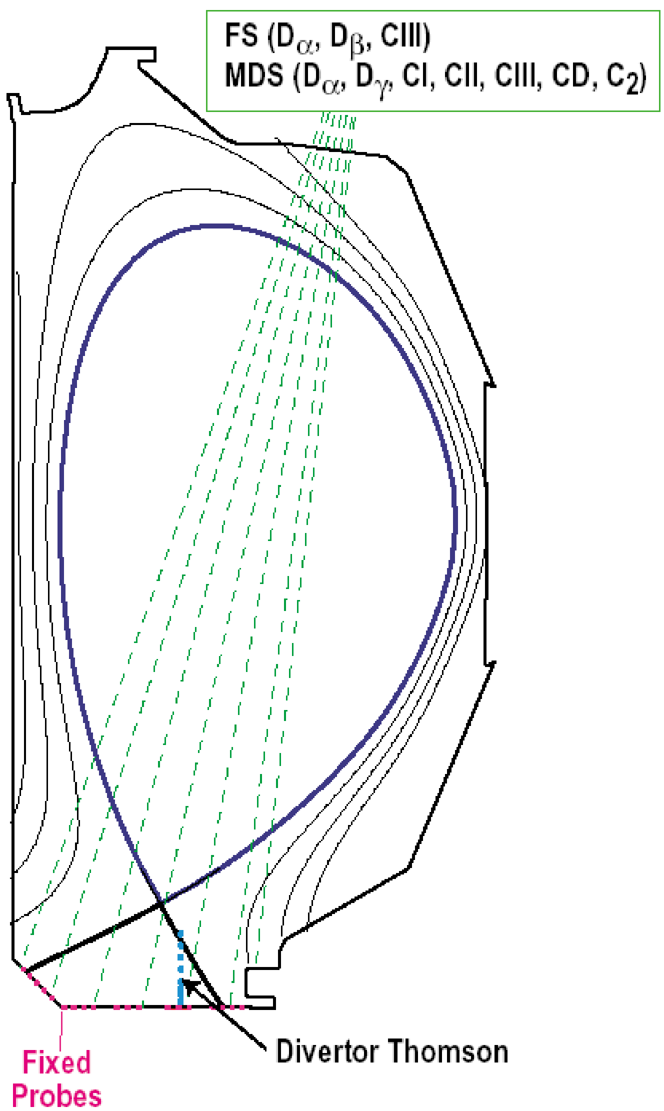
- generate a series of well characterized and diagnosed discharges
- ensure sufficiently simple plasma conditions (e.g. no ELMs) such that interpretation is simplified
- use these discharges in studies of the fundamental physics processes occurring in the divertor, such as chemical sputtering.

The SAPP series of discharges included data for three nominal densities in the main plasma.

- Shots 105500 to 105509 and 105513 $\bar{n}_e \approx 2.5 \times 10^{19}\ m^{-3}$
- Shots 105512, 105514 and 105514 $\bar{n}_e \approx 3.5 \times 10^{19}\ m^{-3}$
- Shots 105516 to 105519 $\bar{n}_e \approx 4.4 \times 10^{19}\ m^{-3}$

What diagnostics are involved in this study?

- target Langmuir probe measurements of I_{sat} and T_e
- Divertor Thomson System (DTS) measurements of the 2D distribution of n_e and T_e near the target
- calibrated spectroscopic measurements of various hydrogenic lines measured by the Filterscopes and MDS spectrometer.

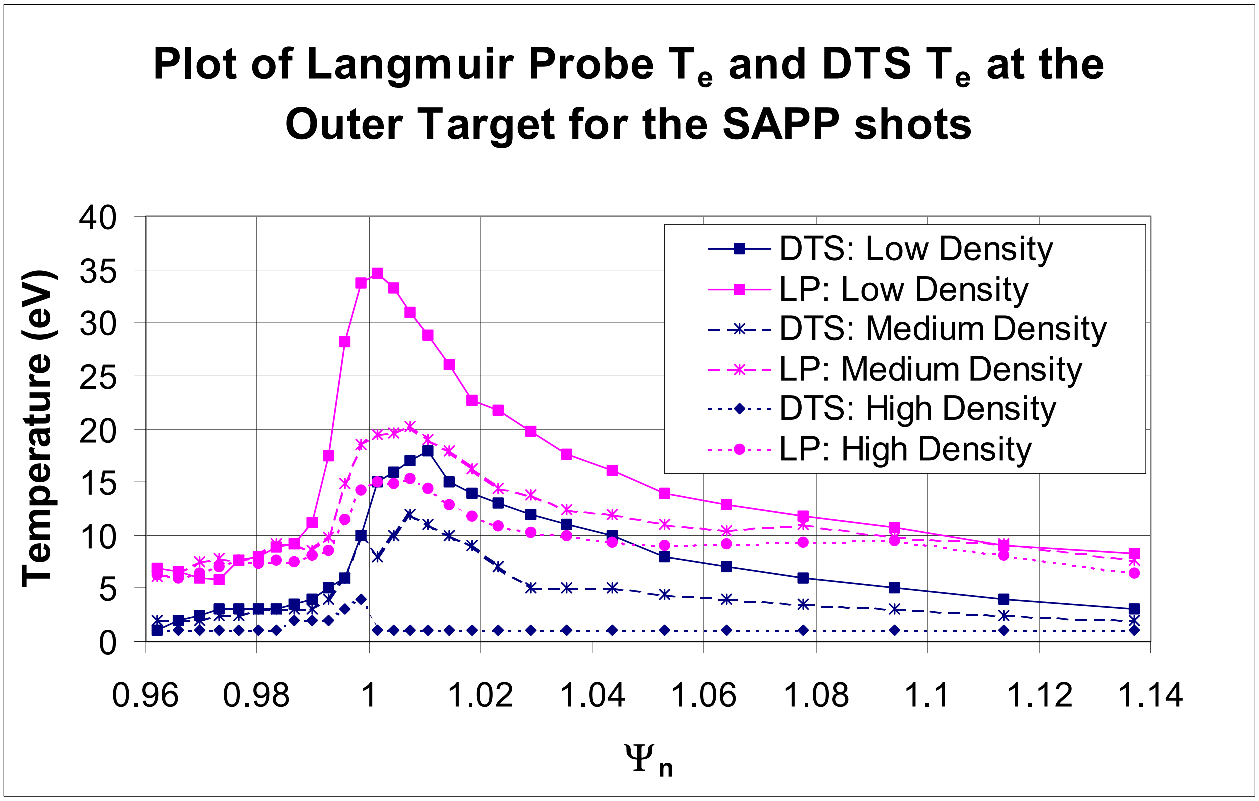


Why is examining T_e important?

- It is not immediately clear, a priori, that the T_e values returned by either the DTS or target probe systems are actually representative of the electron population or are necessarily relevant to the atomic physics processes occurring in the divertor plasma. These processes include excitation, ionization and recombination among others. It is essential to resolve such uncertainties if these SAPP plasmas are to be useable for the planned studies of basic processes occurring in the divertor.
- Plasma fluctuations are a potential concern. It is now known that fluctuations of edge n_e and T_e can be very large in amplitude. Since atomic physics processes are non-linear functions of the n_e and T_e – very strongly so at the low T_e/high n_e of detachment – it is also a possibility that there may be little or no relationship between the time-averaged emission (which is usually all that is measured) and the time-averaged values of n_e and T_e. Lack of such a relationship would considerably complicate interpretive modeling of the divertor, particularly in detachment, perhaps making it impractical.

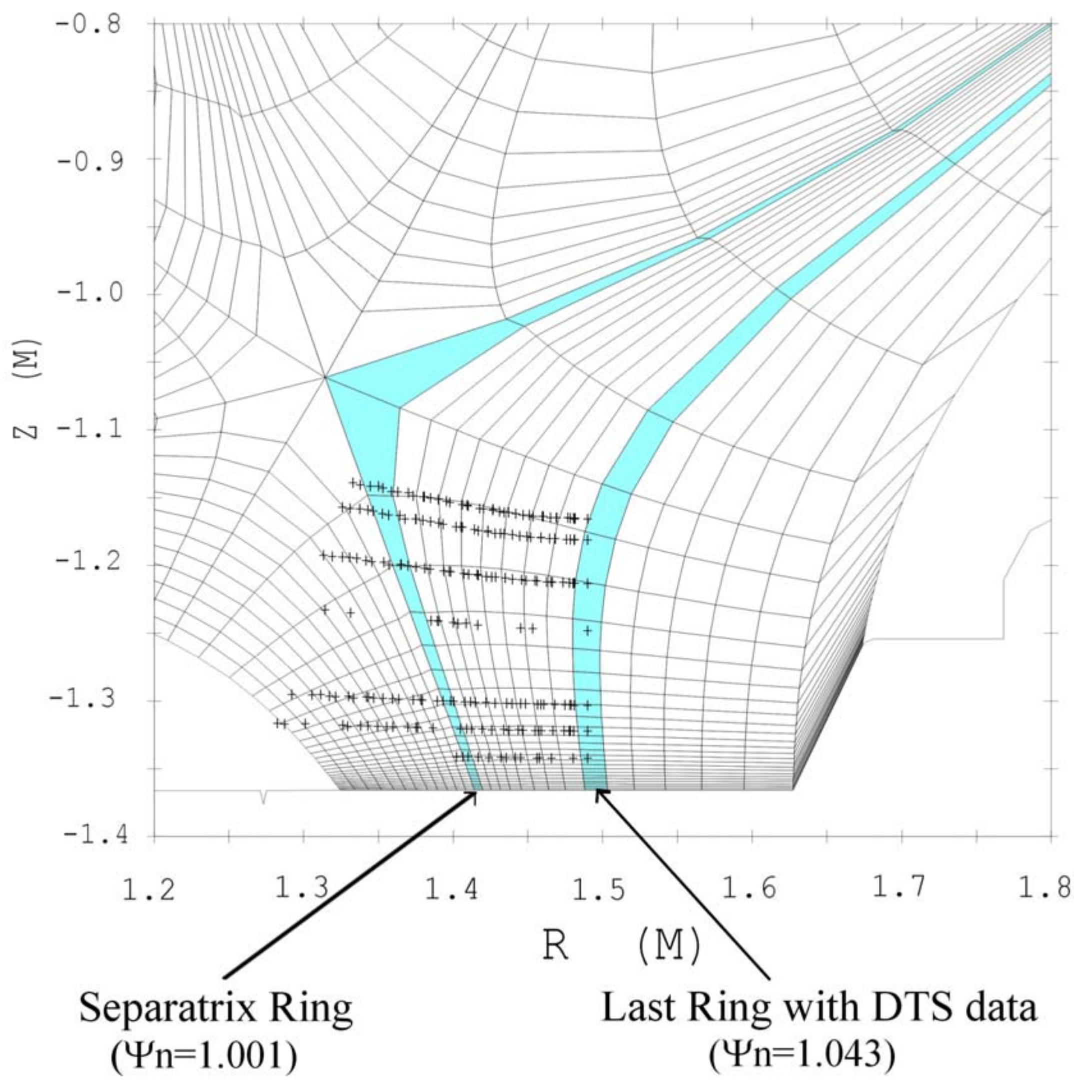
Is there a problem measuring T_e?

- lowest channel DTS measurements (closest to the target) must be carefully assessed due to interpretation concerns resulting from the low temperature energy spectrum and the proximity of the sample locations to the target.
- the T_e measured by the Langmuir probes and that measured by the DTS for the lowest channel differ substantially.



Analysis Procedure

- Assign a 2D OSM (Onion Skin Model) background plasma to the cells on the computational grid (with "rings" as shown here). The 2D n_e and T_e spatial distributions for each of the different SAPP densities were assigned so as to closely match the n_e and T_e measurements made by DTS.



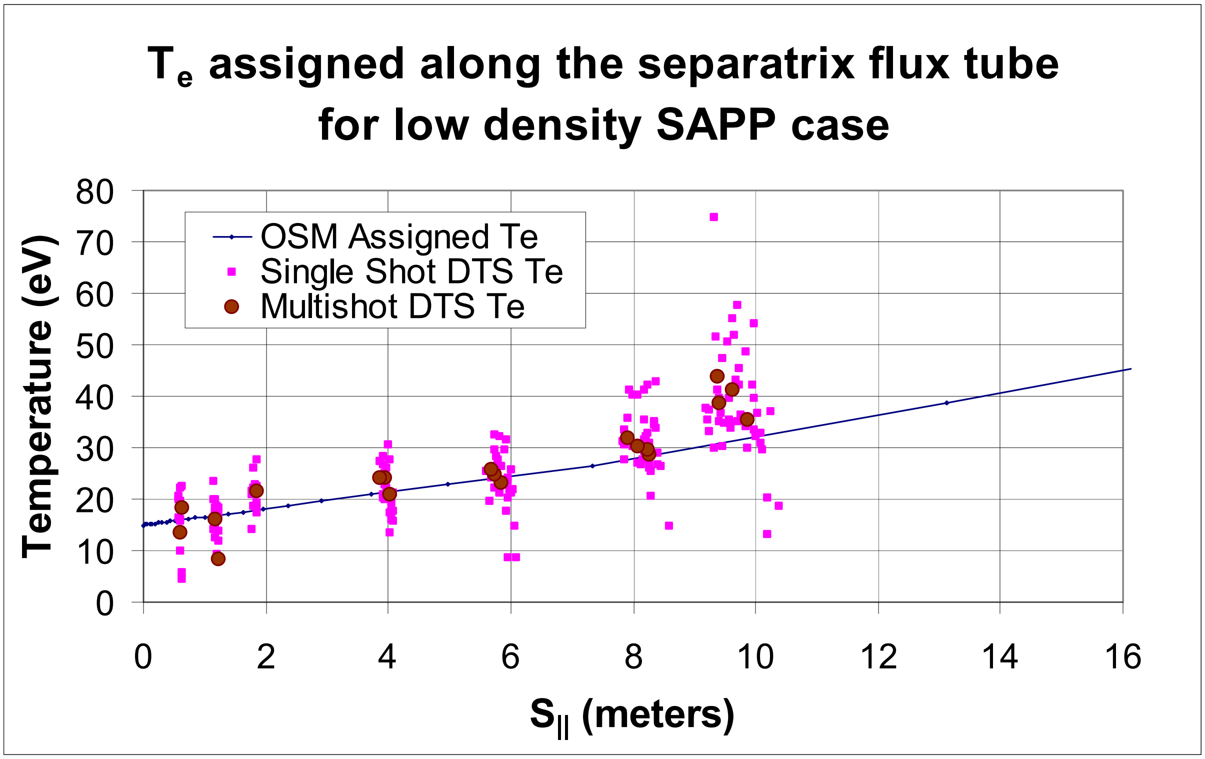
+ DTS sampling points

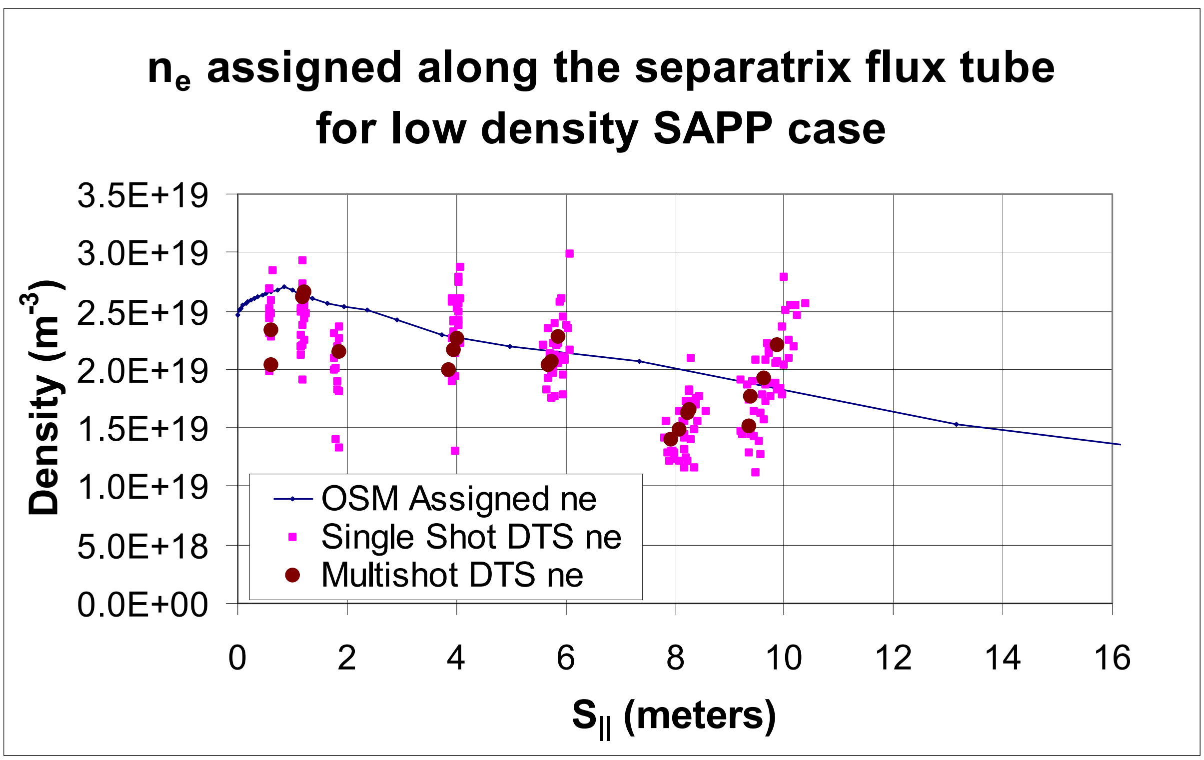
- Since these SAPP runs involved a series of repeated identical shots, a new Thomson analysis procedure was implemented (see B.Bray poster RP1.034 in this session) which combined raw data before analysis. This “Multishot” analysis mode decreased the number of data points rejected because of poor statistics. This analysis mode, however, underestimates the true fluctuation levels which are better indicated by the standard “Single Shot” analysis. Both types of DTS results are shown in the following figures.
- The neutral hydrogen Monte Carlo code EIRENE was used, with the assigned background plasma and with the I_{sat} from the Langmuir probes (to give the absolute recycling flux) to calculate the spatial profiles of the deuterium emission.

The following figures show:

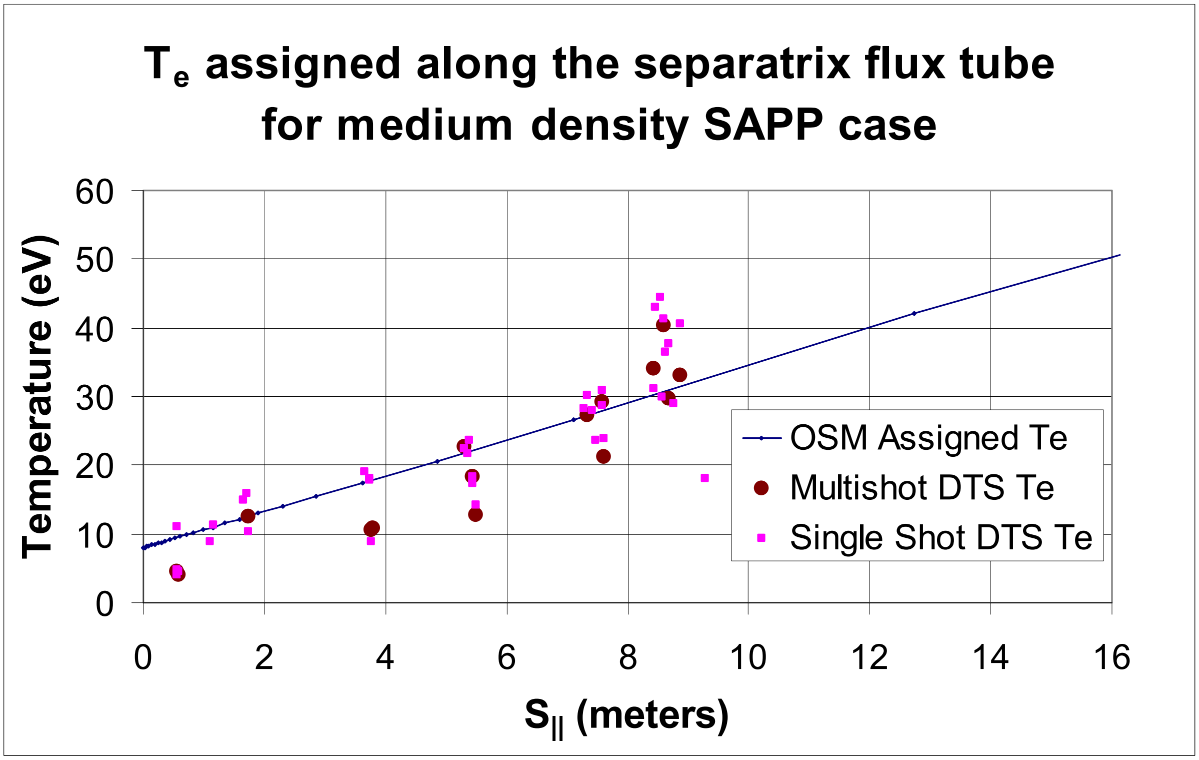
- the plasma conditions assigned along the separatrix ring of the grid (i.e. $n_e(s_{||})$ and $T_e(s_{||})$) for the “base” plasma background. These values are the ones chosen to match the actual DTS data.
- the comparison of the code calculated and experimental spectroscopic signals for the “base” case plasma conditions.

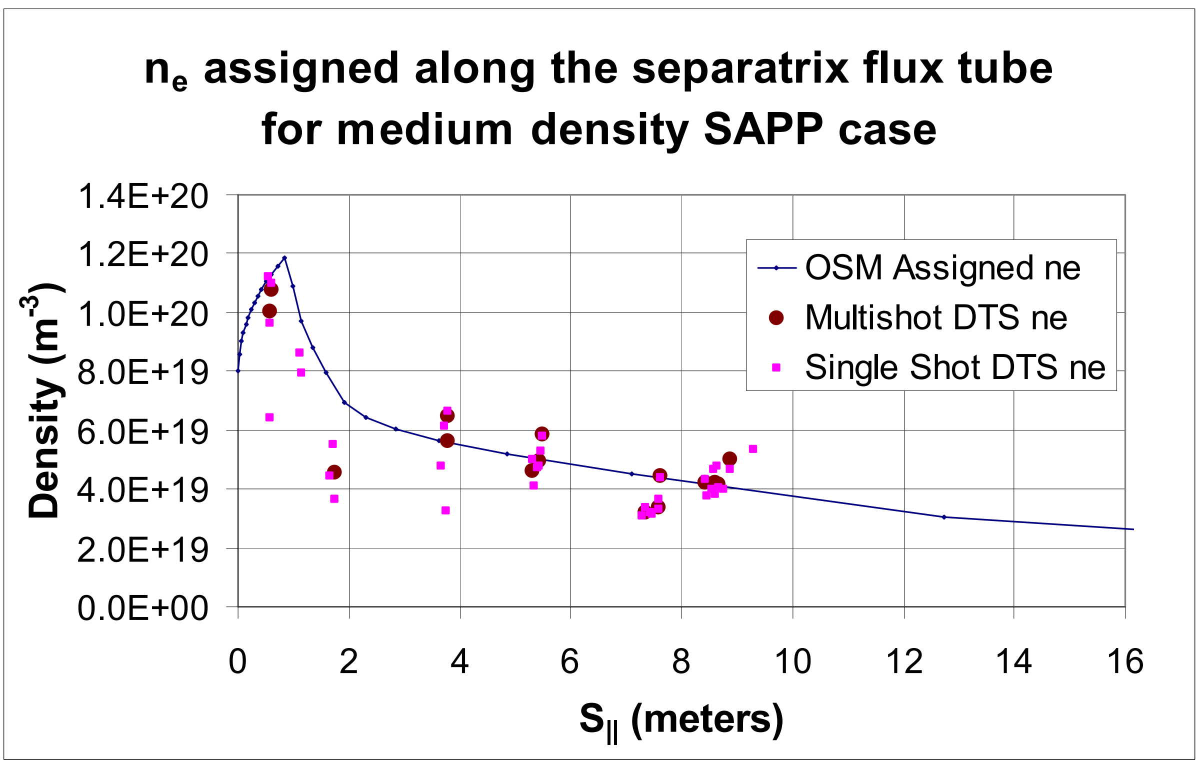
Separatrix Plasma for Low Density SAPP



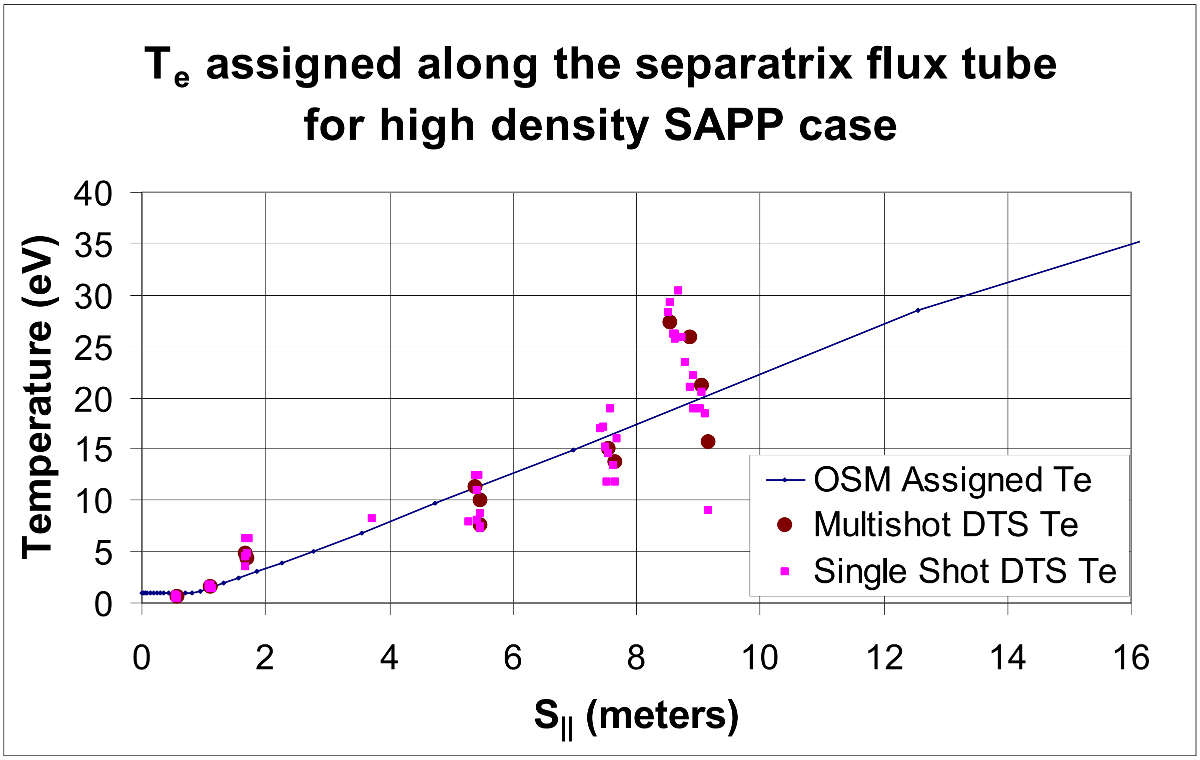


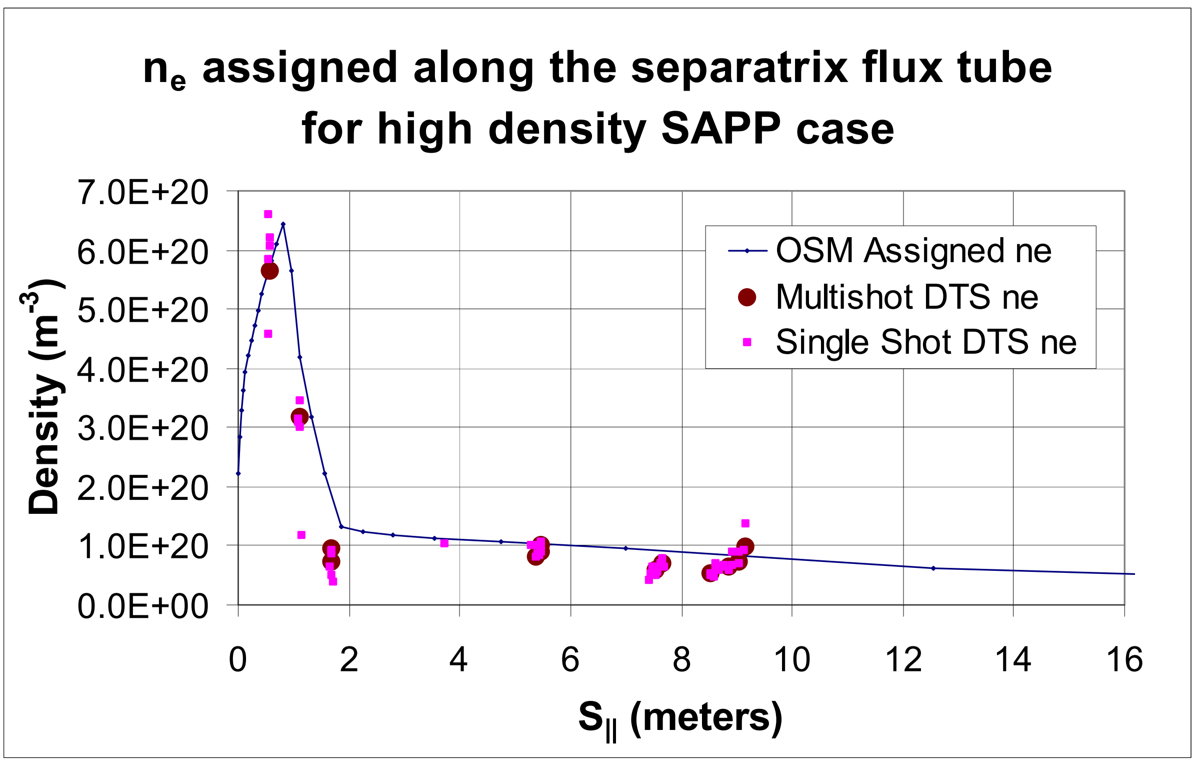
Separatrix Plasma for Medium Density SAPP





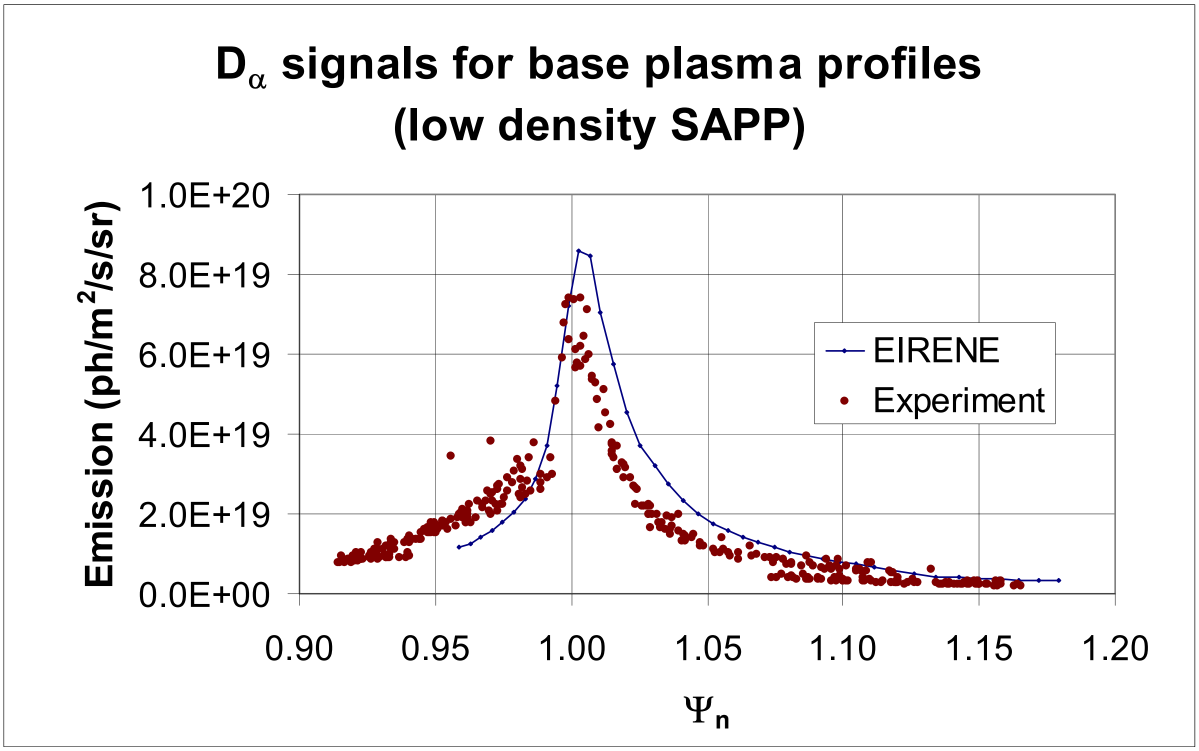
Separatrix Plasma for High Density SAPP

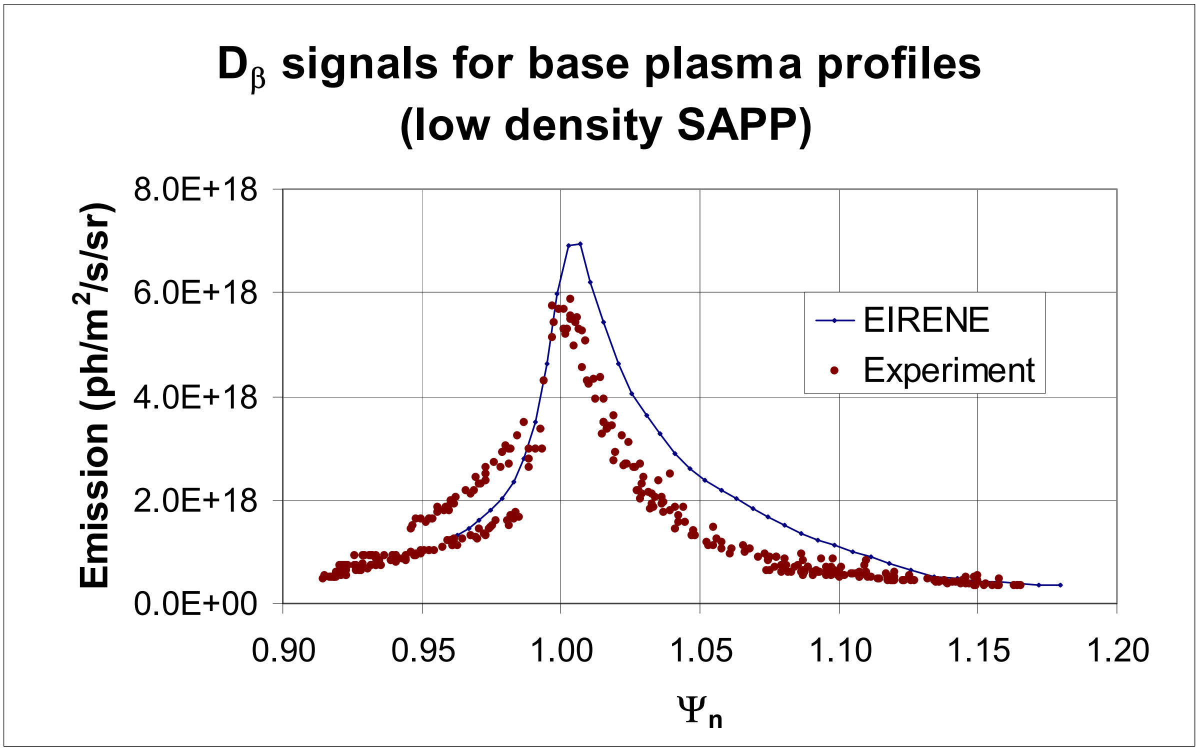




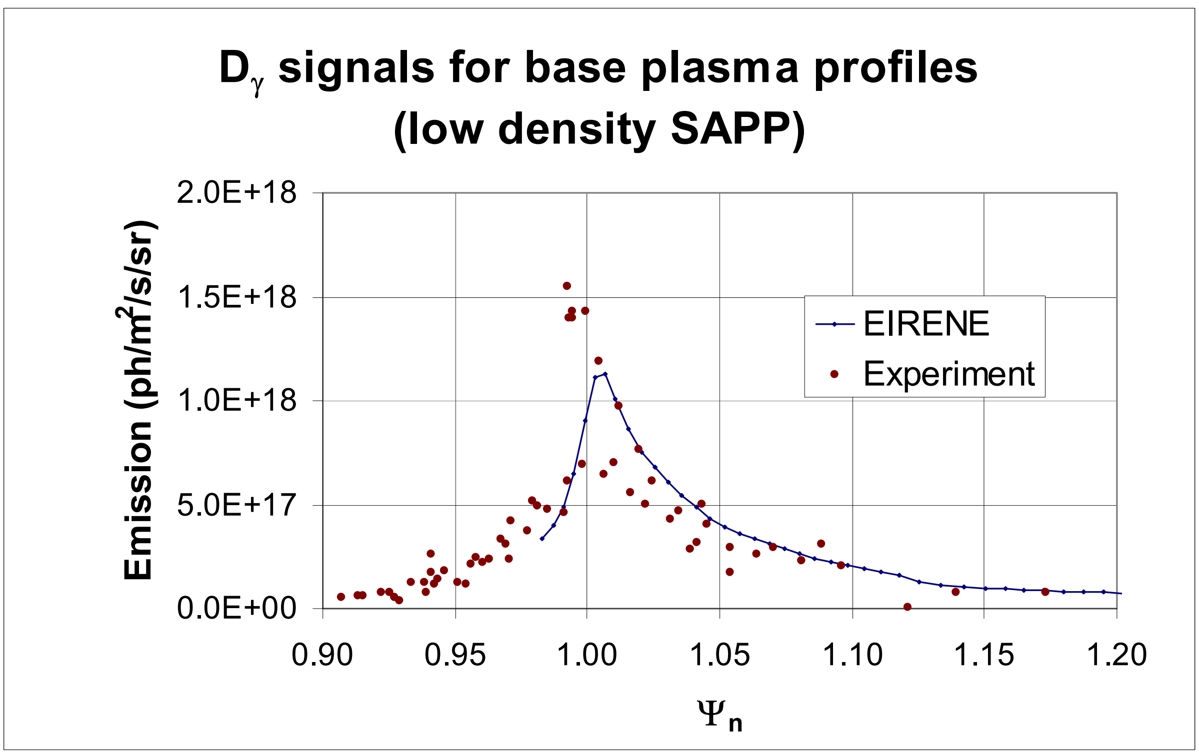
Spectroscopic Comparisons for Low Density SAPP

- Good agreement with the hydrogenic spectroscopic measurements for the low and medium density SAPP cases was found when using the 2D background plasma that matched the DTS measurements.



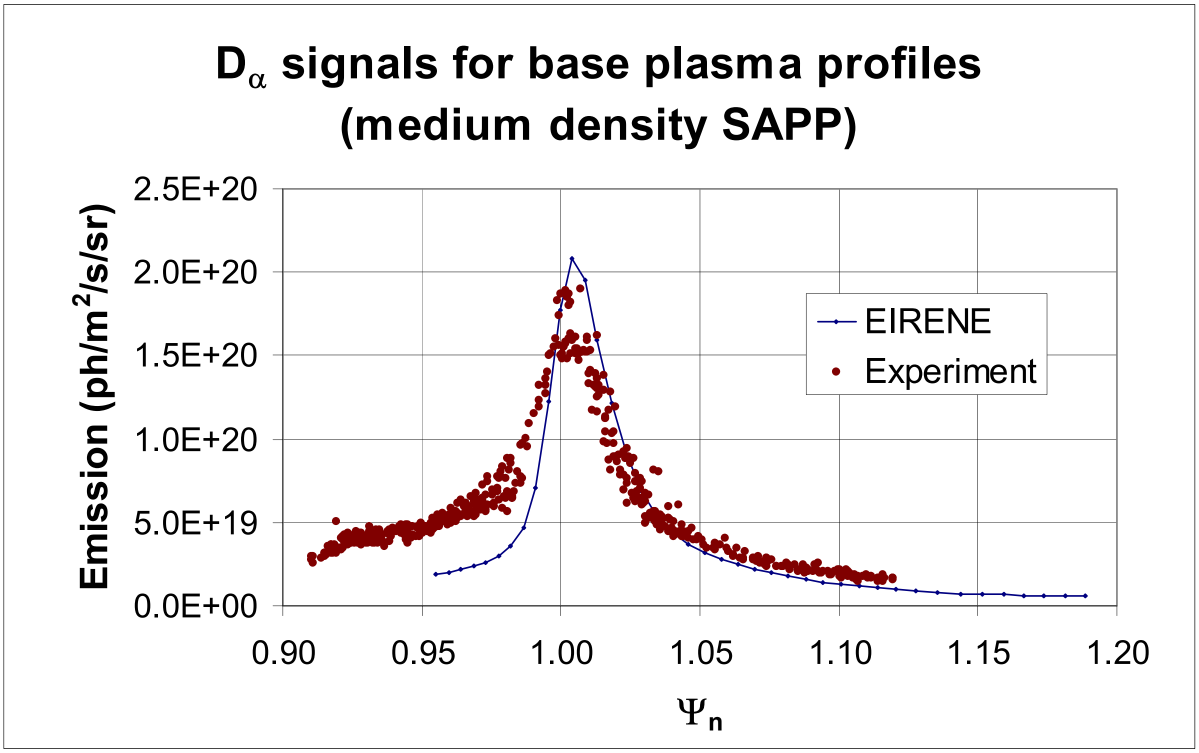


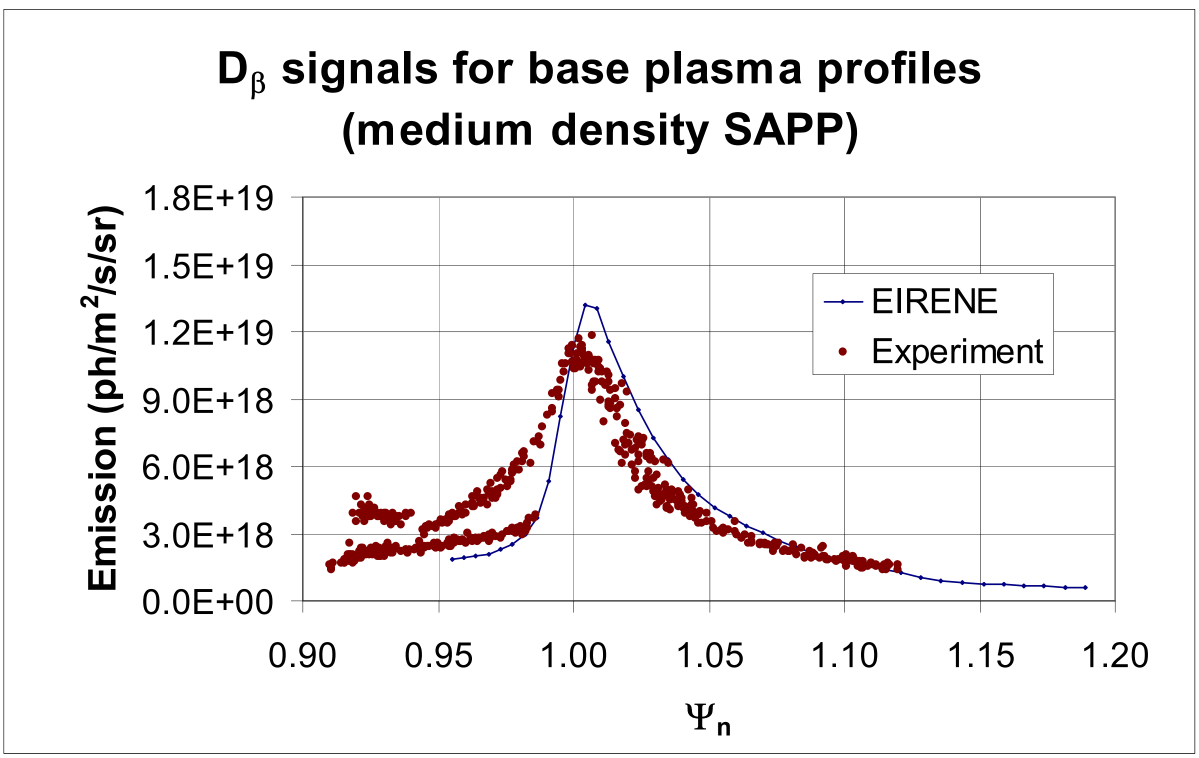
Dβ signals for base plasma profiles
(low density SAPP)
Emission (ph/m2/s/sr)
8.0E+18
6.0E+18
4.0E+18
2.0E+18
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψn
EIRENE
Experiment



Dγ signals for base plasma profiles
(low density SAPP)
Emission (ph/m2/s/sr)
2.0E+18
1.5E+18
1.0E+18
5.0E+17
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψn
EIRENE
Experiment

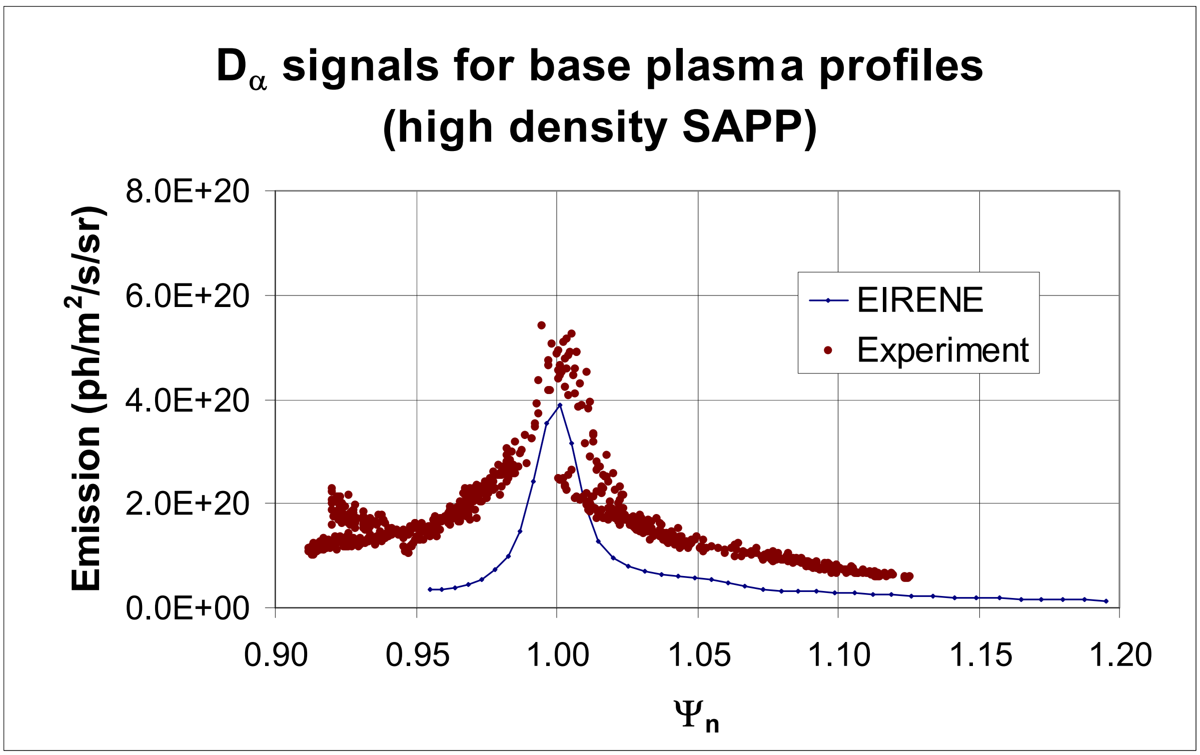
Spectroscopic Comparisons for Medium Density SAPP

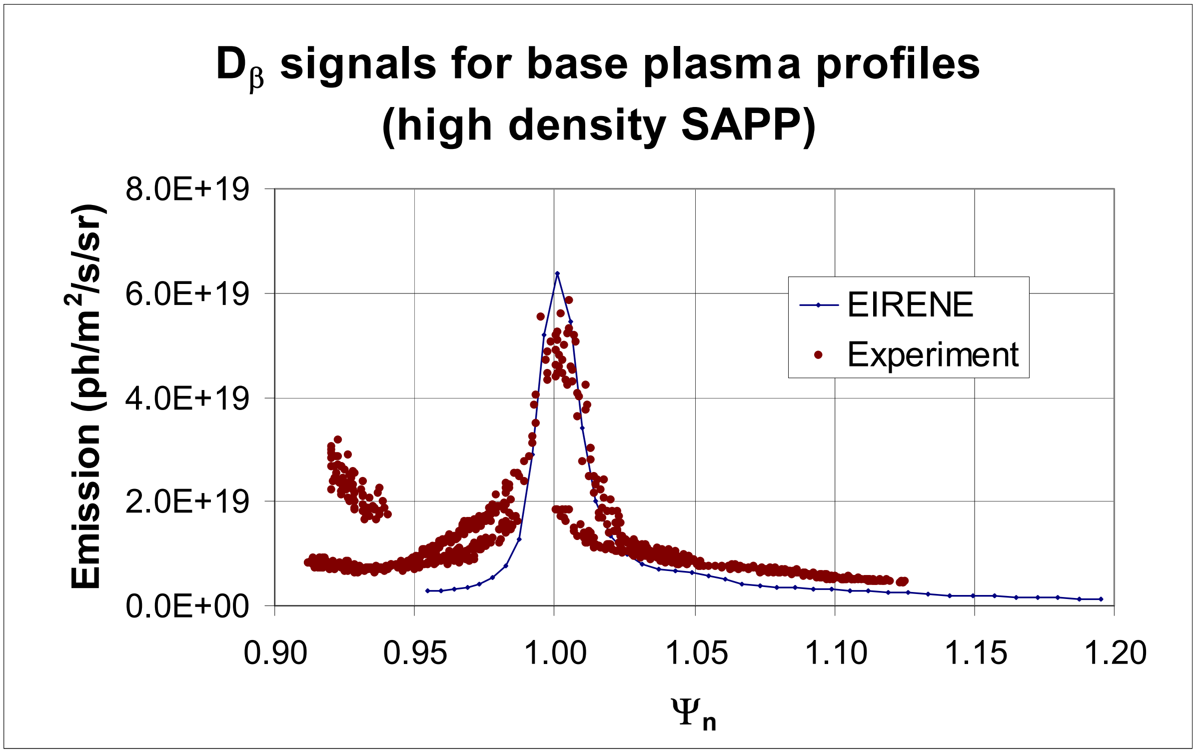




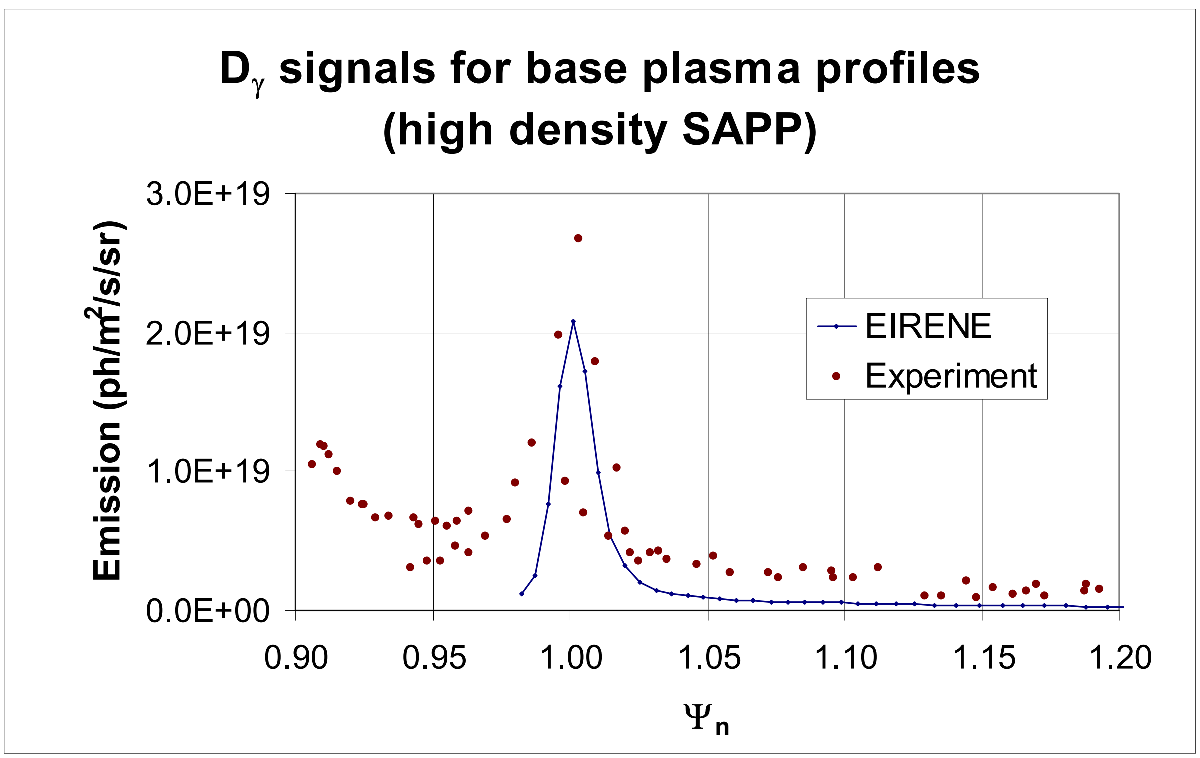
Spectroscopic Comparisons for High Density SAPP

- A quite reasonable match to the spectroscopy was also found for the high density SAPP case using plasma conditions matching the DTS data.





Dβ signals for base plasma profiles
(high density SAPP)
Emission (ph/m2/s/sr)
8.0E+19
6.0E+19
4.0E+19
2.0E+19
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψn
EIRENE
Experiment



Dγ signals for base plasma profiles
(high density SAPP)
Emission (ph/m2/s/sr)
3.0E+19
2.0E+19
1.0E+19
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψn
EIRENE
Experiment

Sensitivity of Spectroscopic Measurements

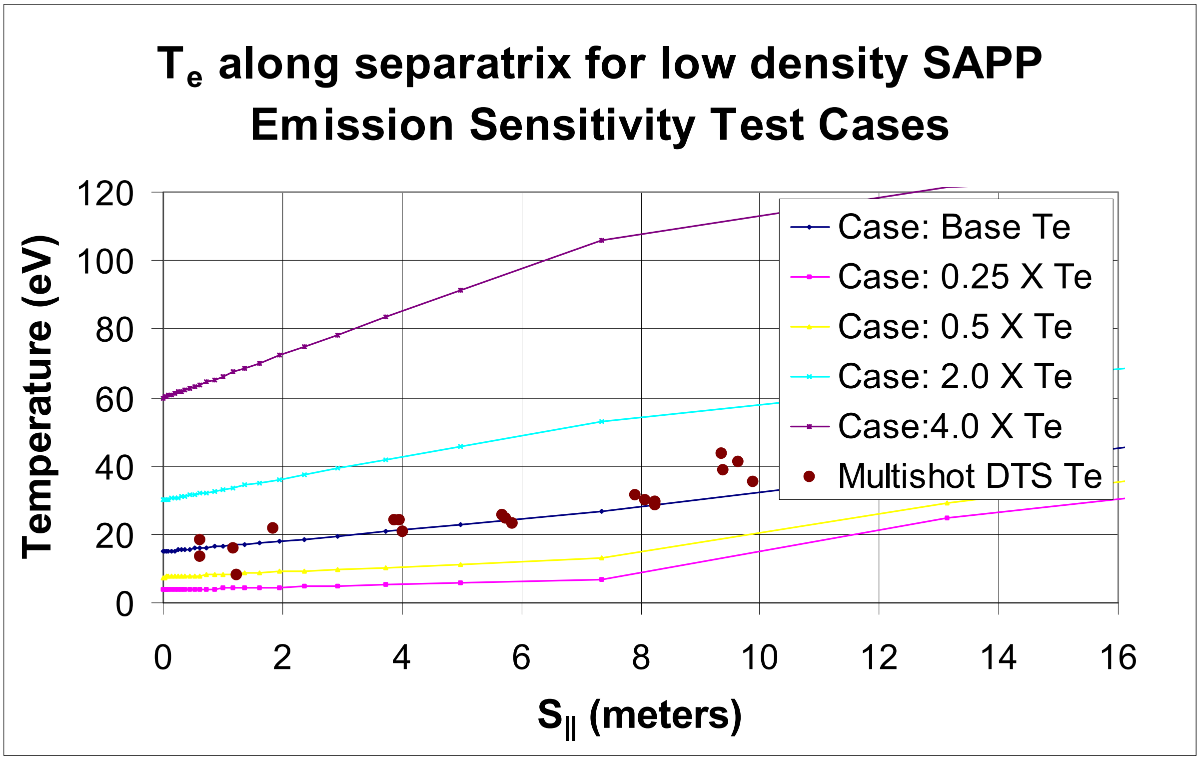
- The results above show that the DTS measurements, the Langmuir probe I_{sat} and the spectroscopic measurements are quite self-consistent. Spectroscopic profiles are obtained from the simulations, which match fairly closely, those seen experimentally.
- The results presented so far do not address the question of the sensitivity of the spectroscopic results to the plasma conditions nor do they necessarily support the choice of DTS T_e measurements over the Langmuir probe values.

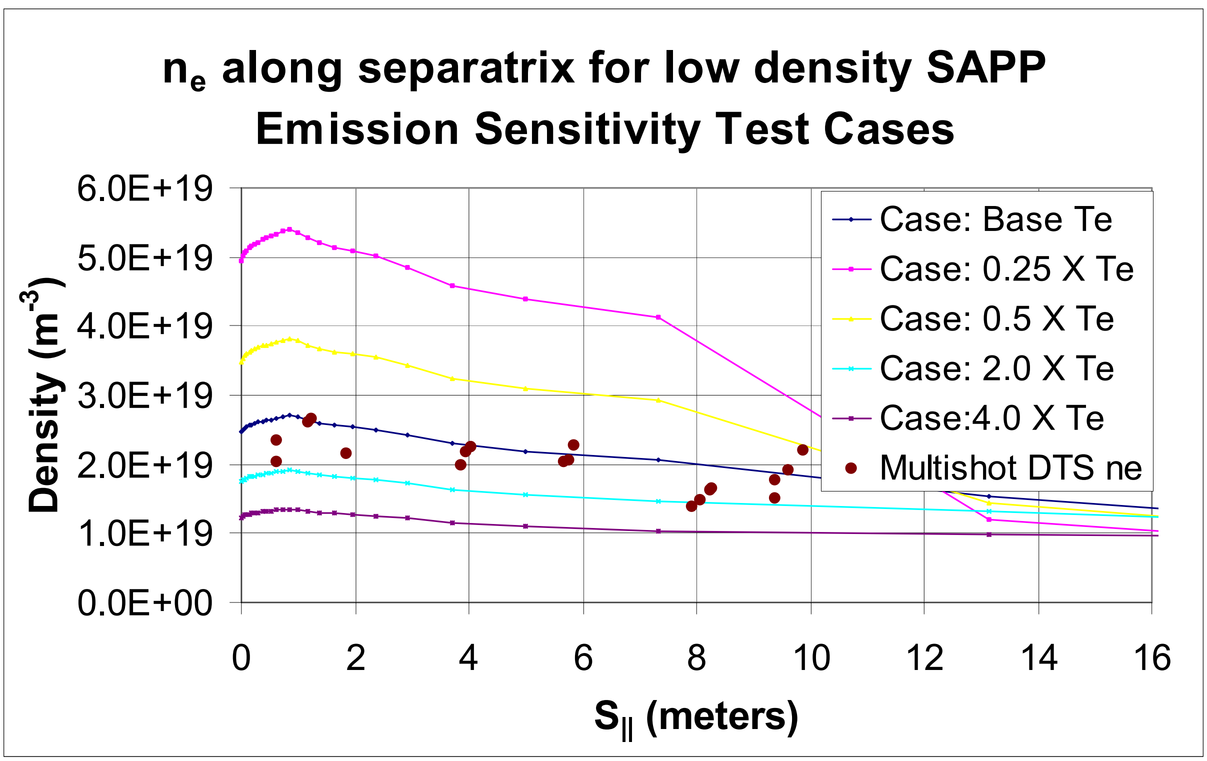
Examining the Sensitivty of the Spectroscopic Signals

- A series of simulations was run for each SAPP density with a large variation in the plasma conditions between cases.
- The target I_{sat} was left fixed since the hydrogenic spectroscopic signals are directly related to the hydrogen influx.
- The target temperature was changed by factors of 0.25, 0.5, 2.0 and 4.0 relative to the base case.

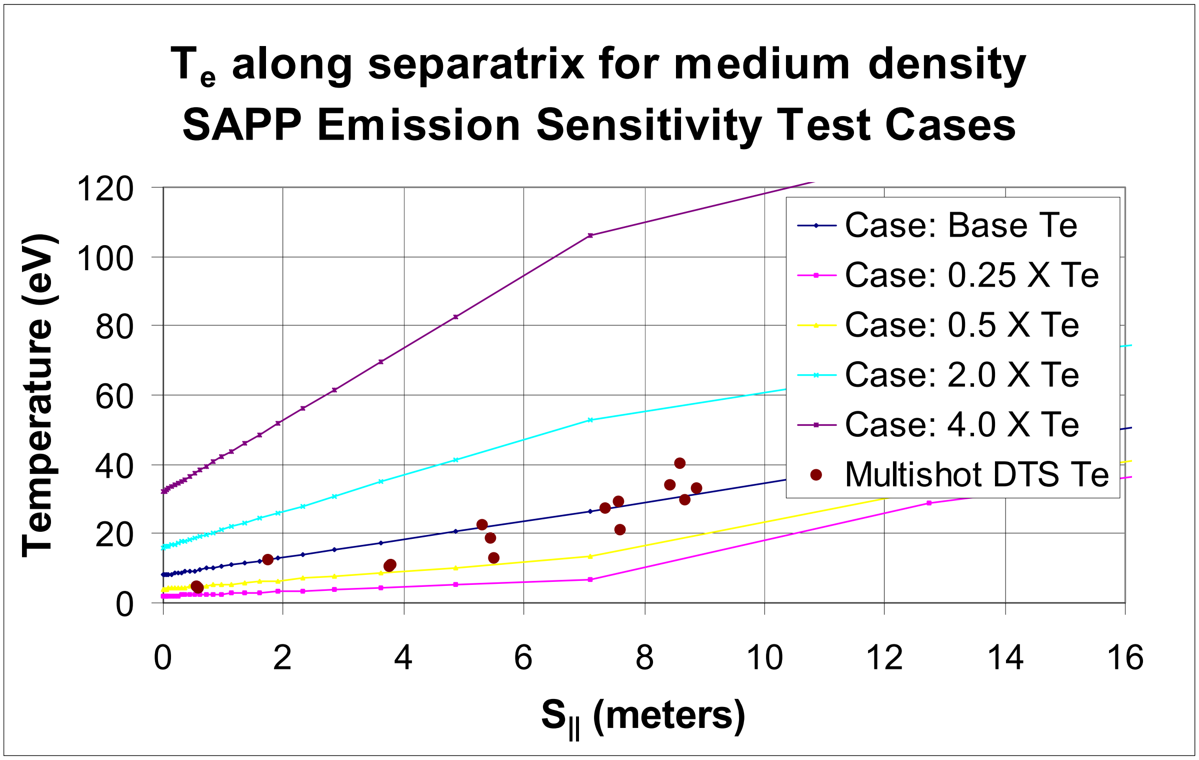
Figures showing the plasma conditions on the separatrix ring are shown below.

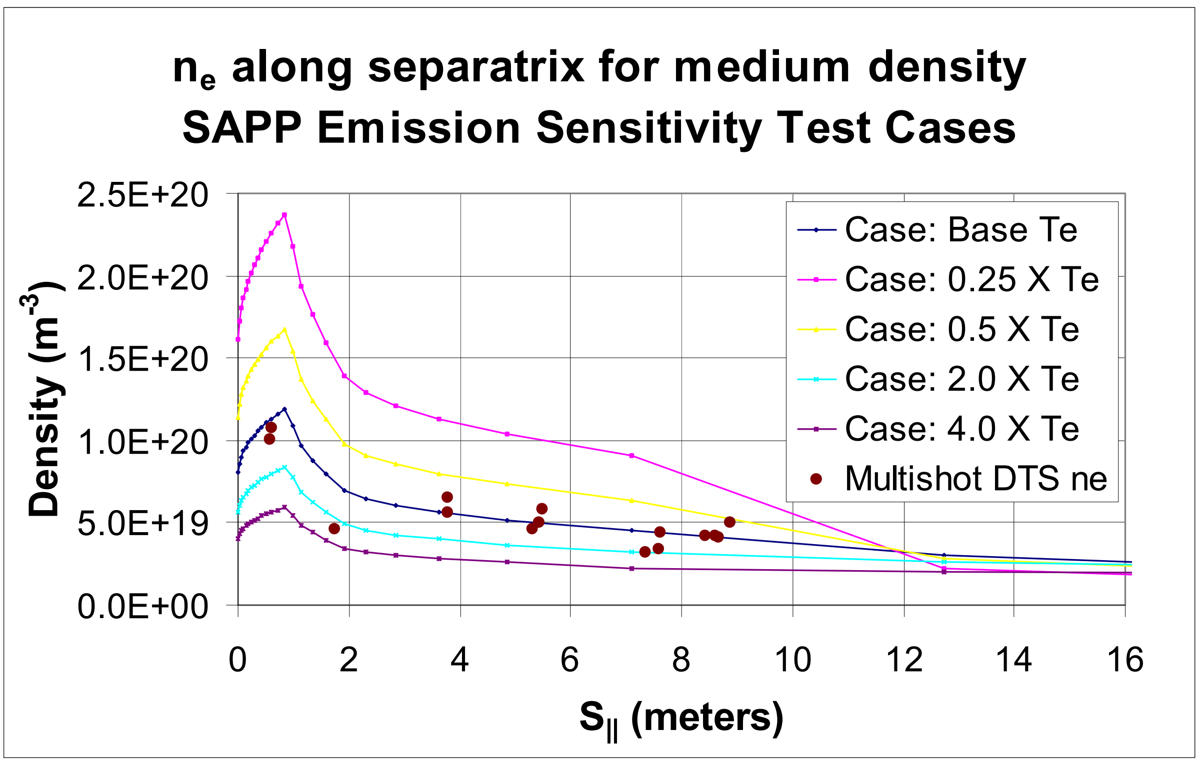
Sensitivity Scan Plasma Profiles for Low Density SAPP



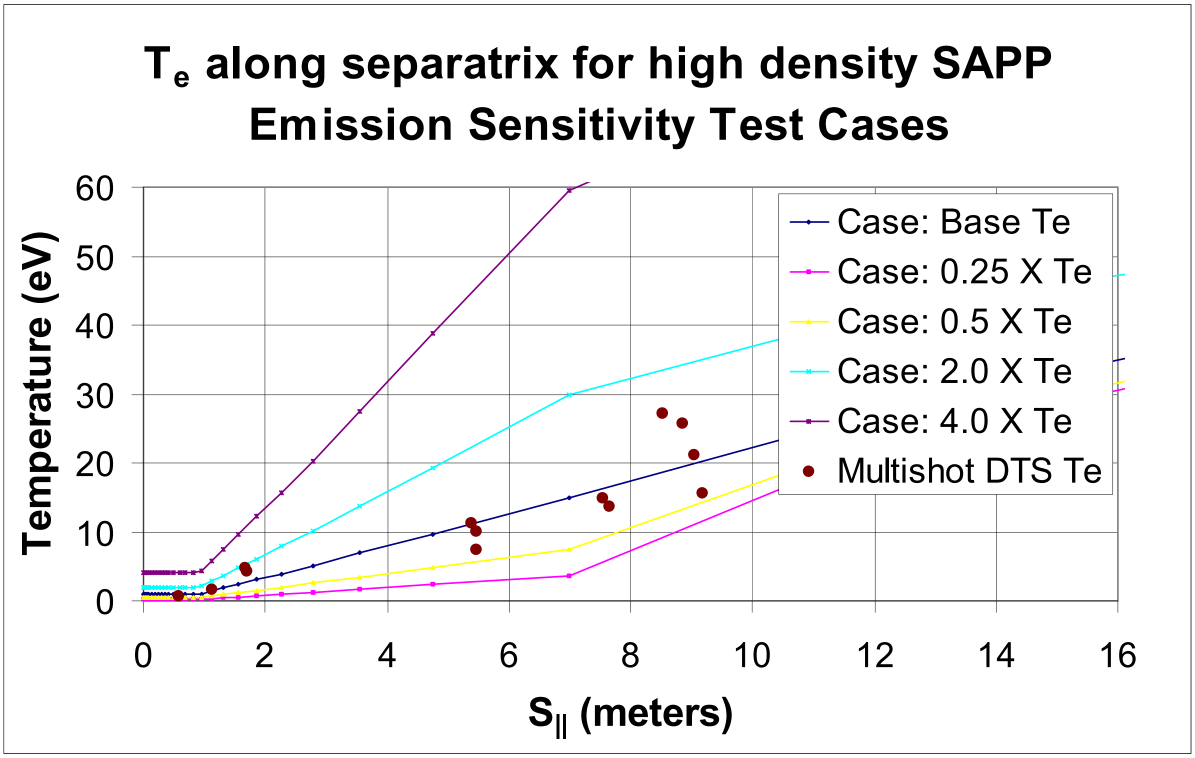


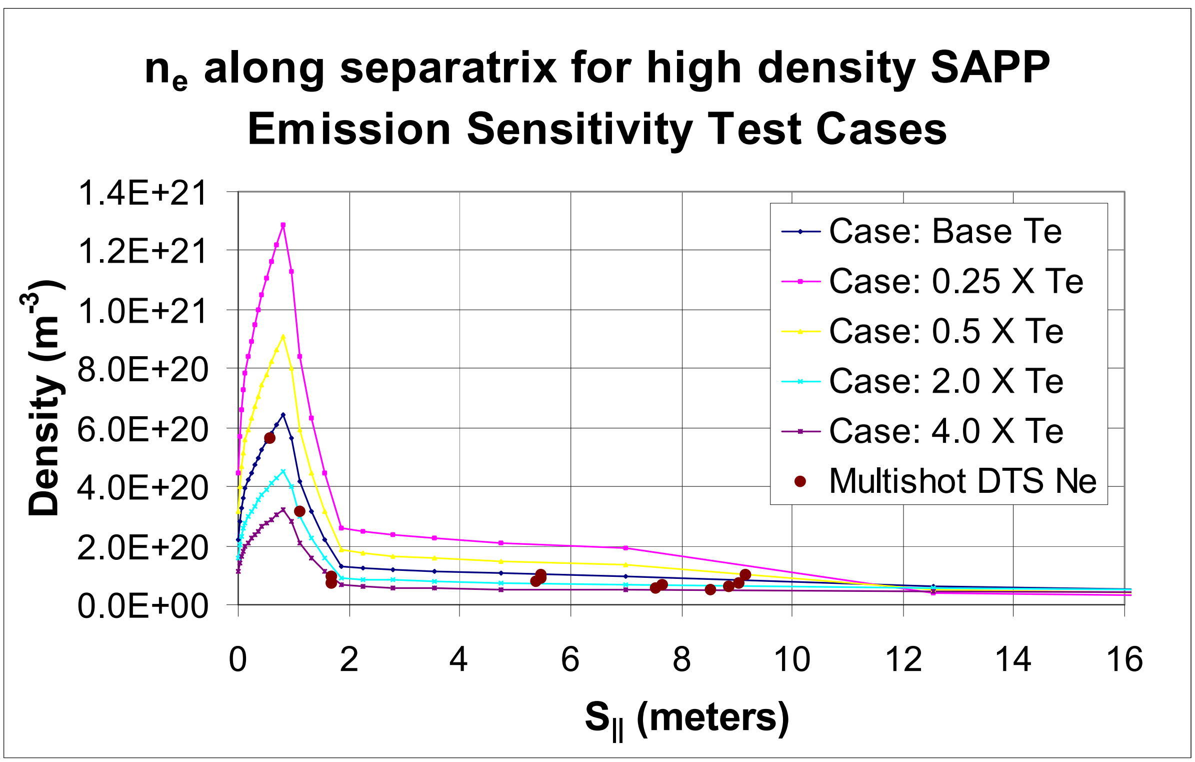
Sensitivity Scan Plasma Profiles for Medium Density SAPP





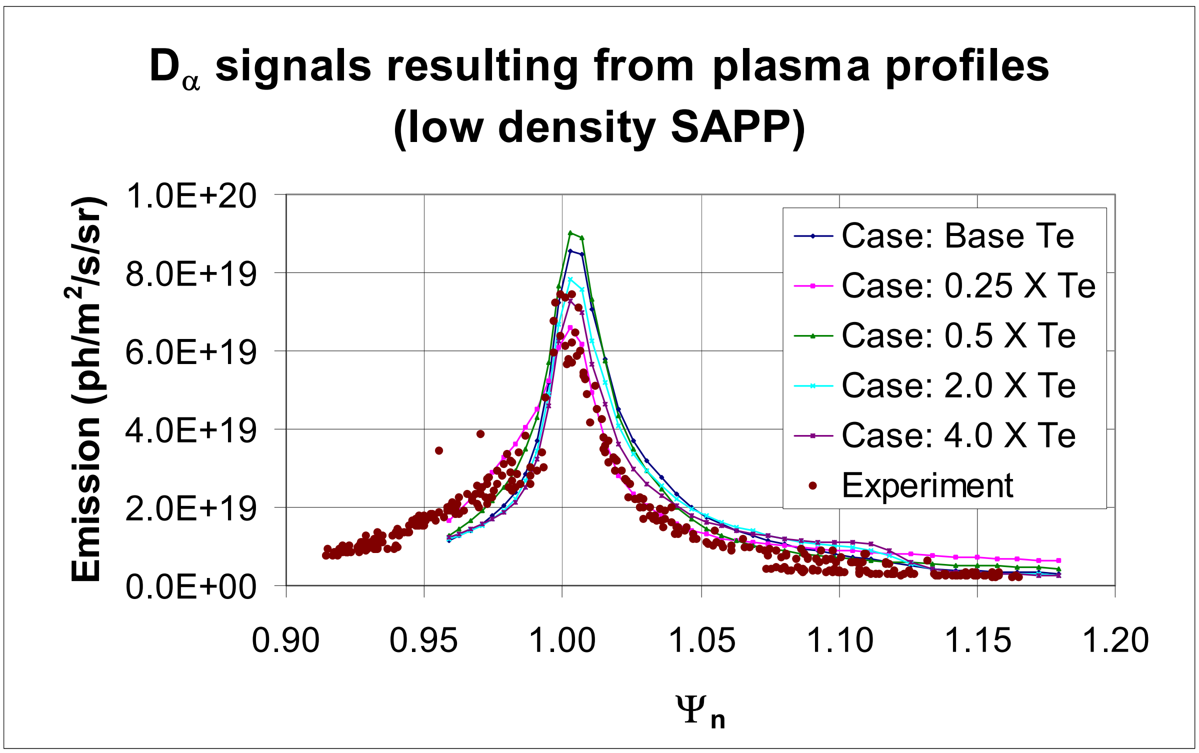
Sensitivity Scan Plasma Profiles for High Density SAPP

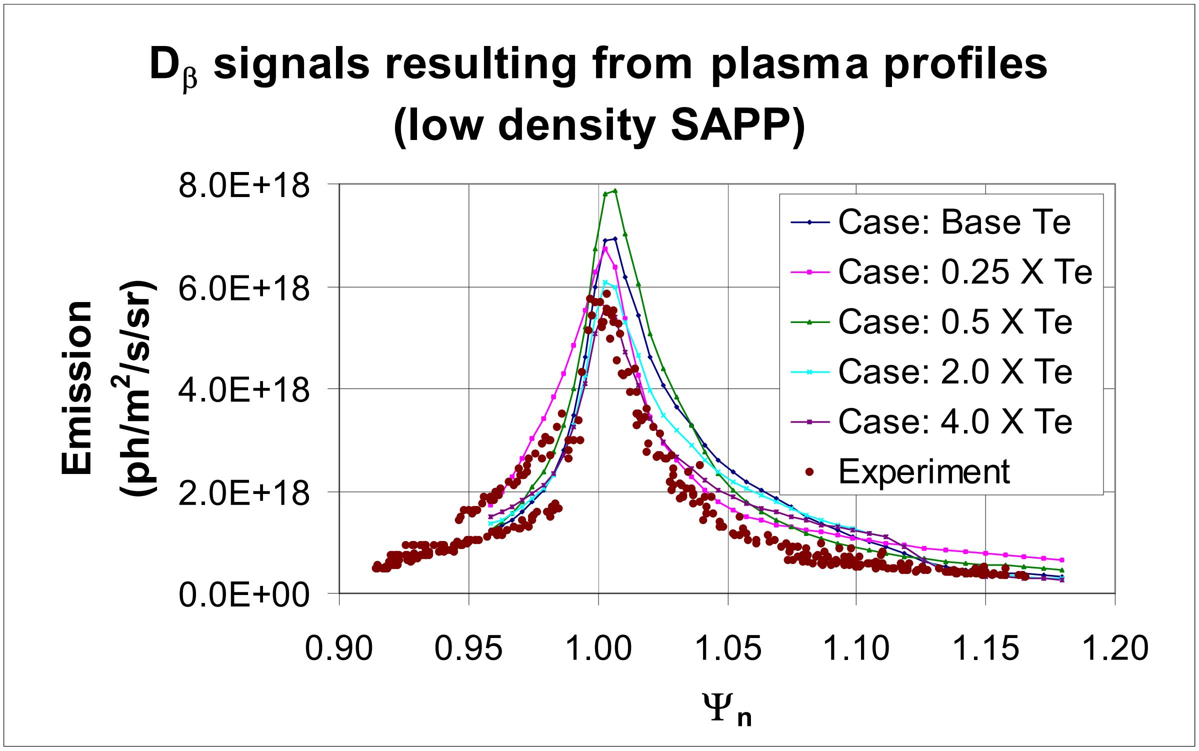




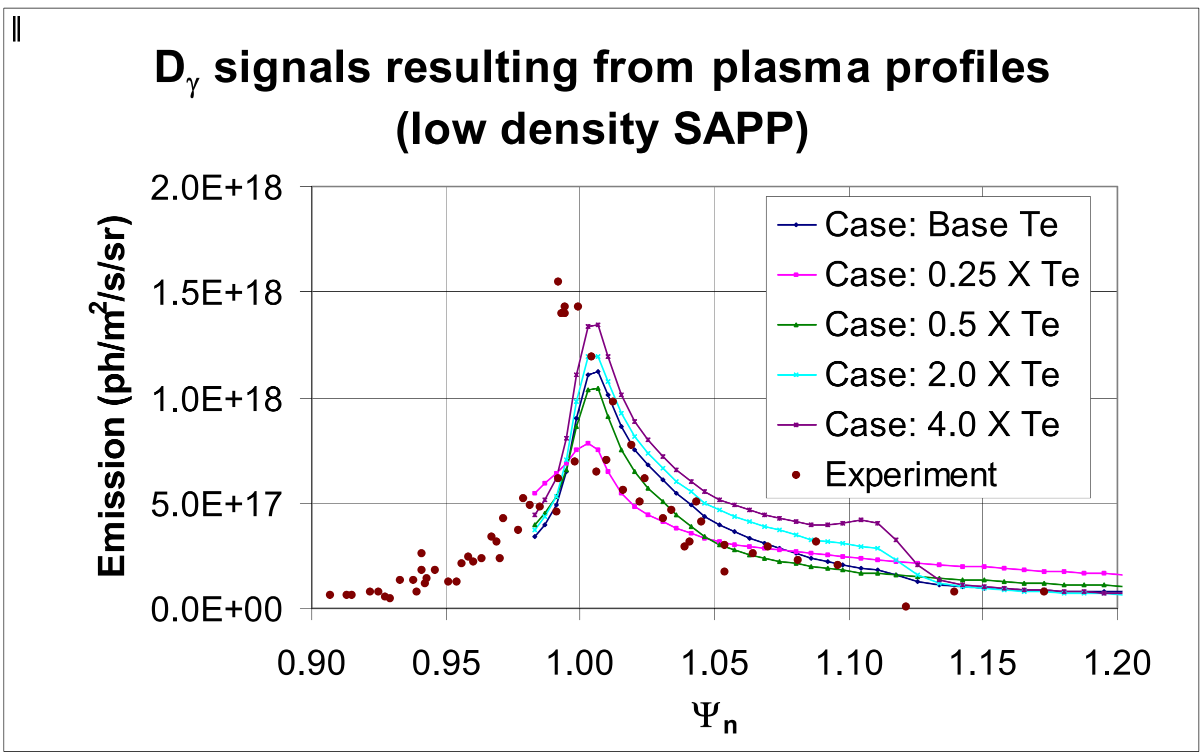
Emission from Sensitivity Scan plasma conditions for Low Density SAPP

- Large changes in the background plasma result in relatively small changes in the calculated emission for the low and medium density SAPP conditions.



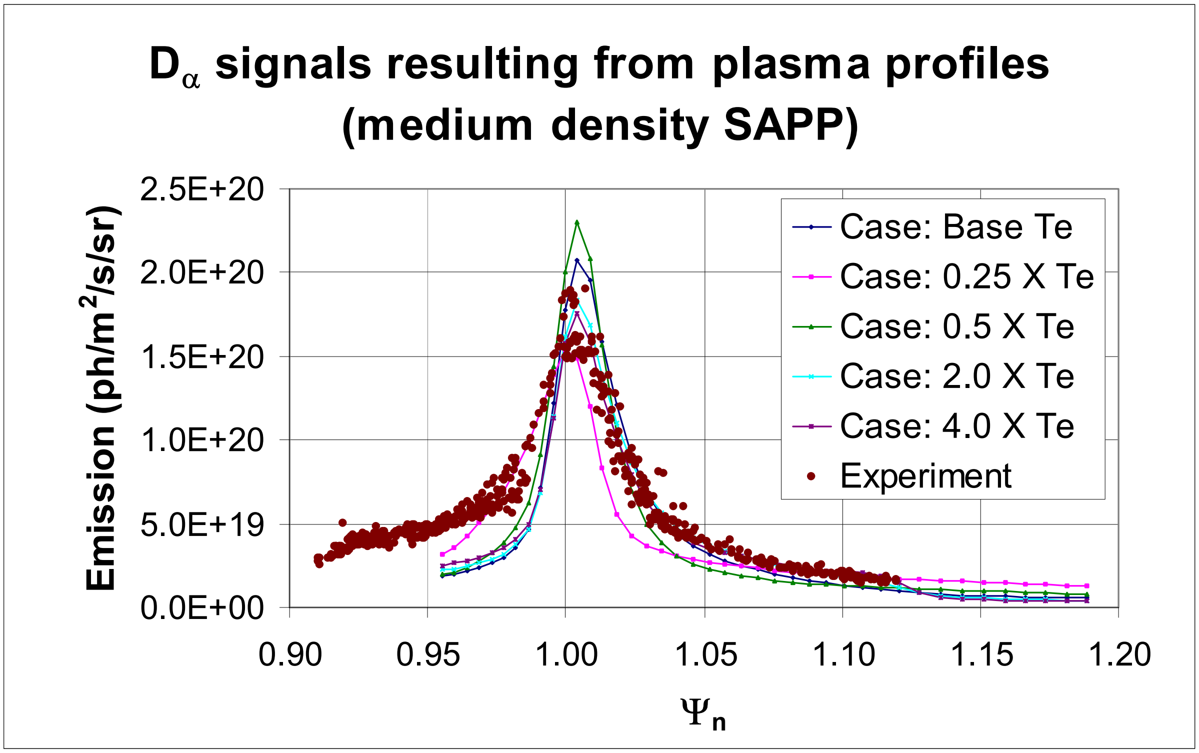


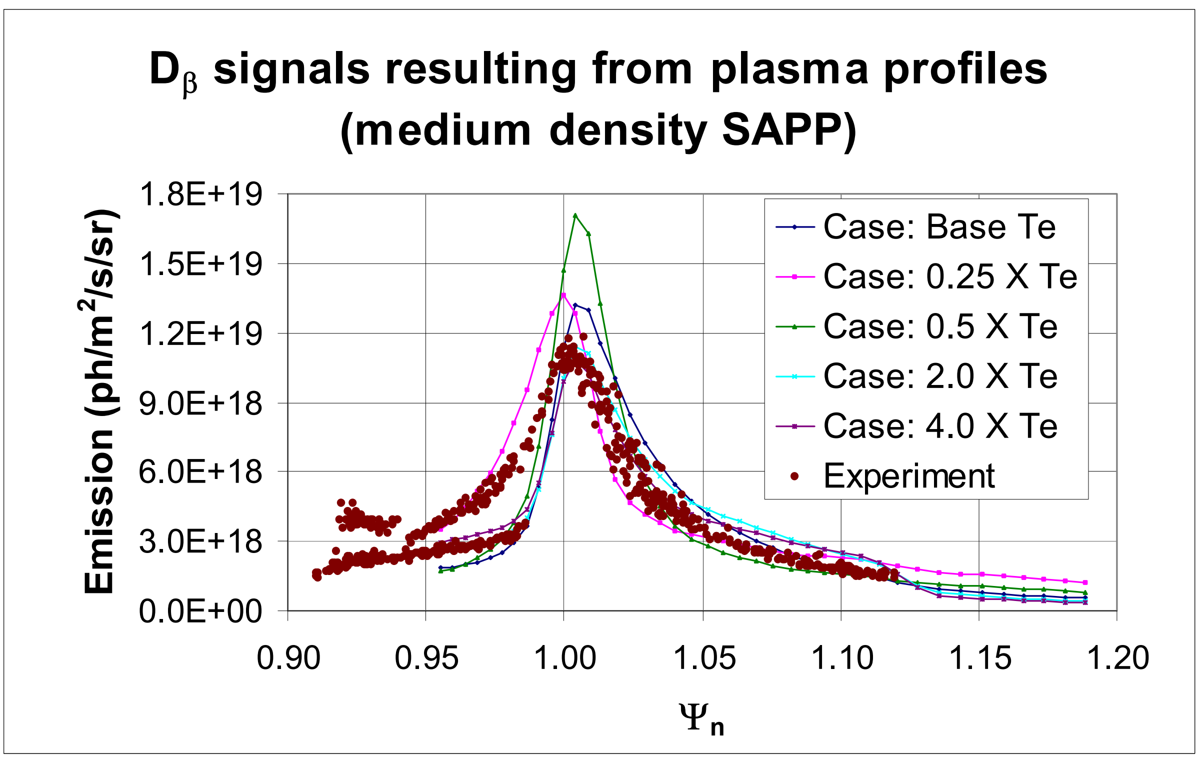
D_β signals resulting from plasma profiles
(low density SAPP)
Emission (ph/m²/s/sr)
8.0E+18
6.0E+18
4.0E+18
2.0E+18
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψ_n
Case: Base Te
Case: 0.25 X Te
Case: 0.5 X Te
Case: 2.0 X Te
Case: 4.0 X Te
Experiment



D_γ signals resulting from plasma profiles
(low density SAPP)
Emission (ph/m²/s/sr)
2.0E+18
1.5E+18
1.0E+18
5.0E+17
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψ_n
Case: Base Te
Case: 0.25 X Te
Case: 0.5 X Te
Case: 2.0 X Te
Case: 4.0 X Te
Experiment

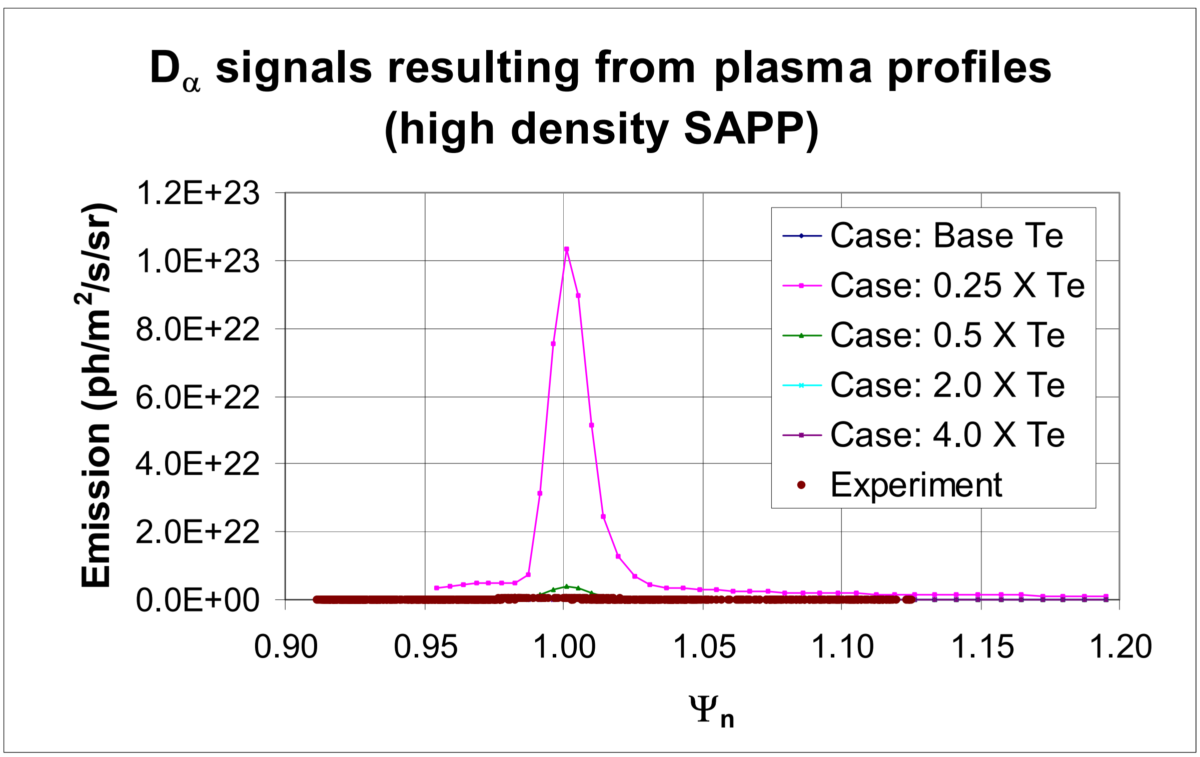
Emission from Sensitivity Scan plasma conditions for Medium Density SAPP

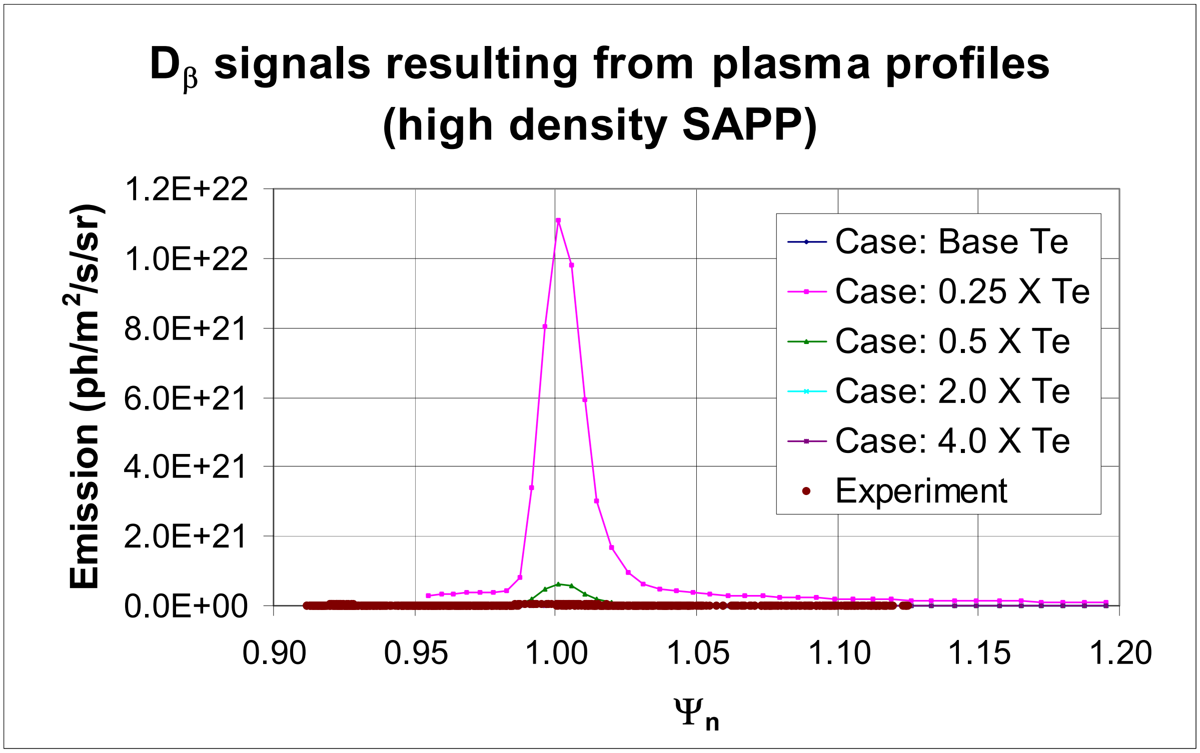


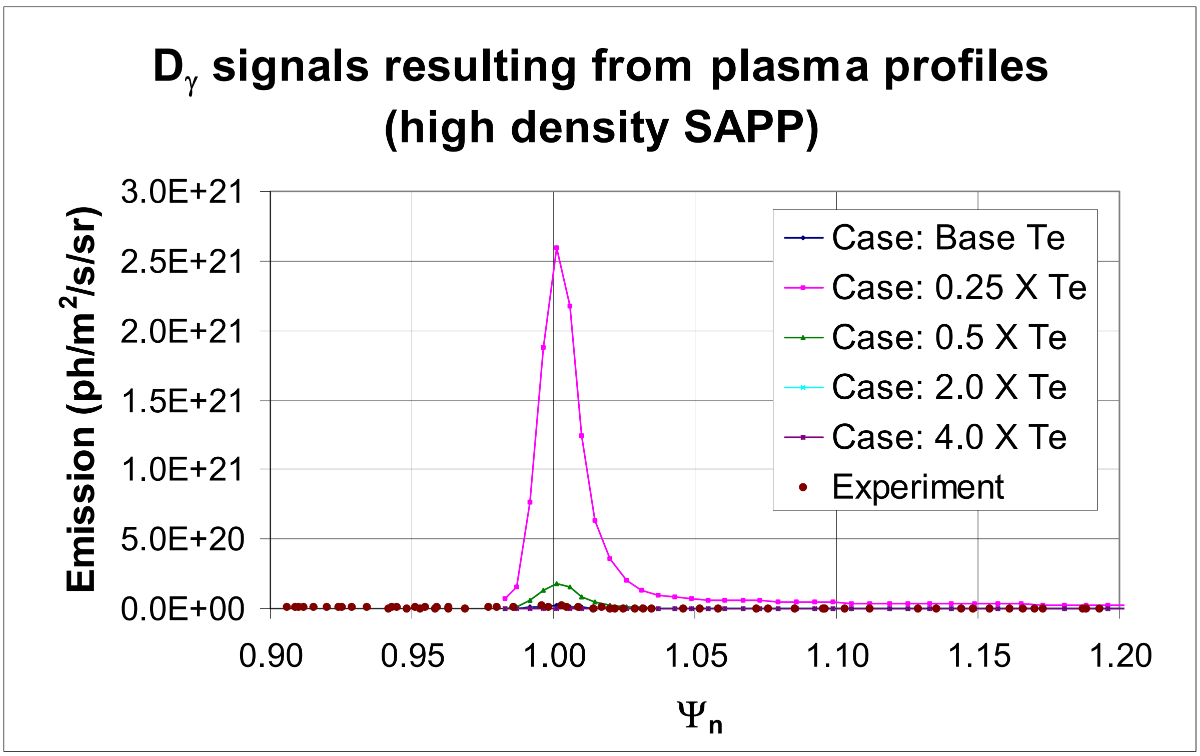


Emission from Sensitivity Scan plasma conditions for High Density SAPP

- The same scale of changes when applied in to the High Density SAPP conditions has a much greater effect on the emission.
- Two sets of plots with different scaling are required to show the range of results.

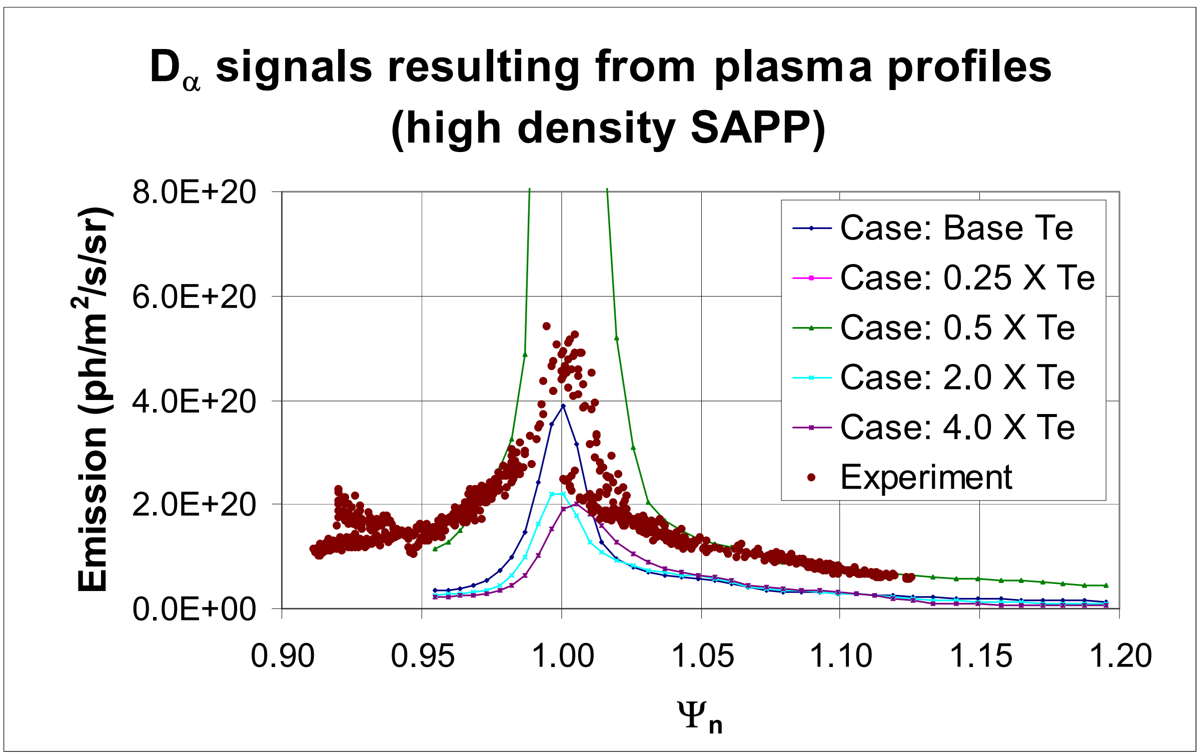


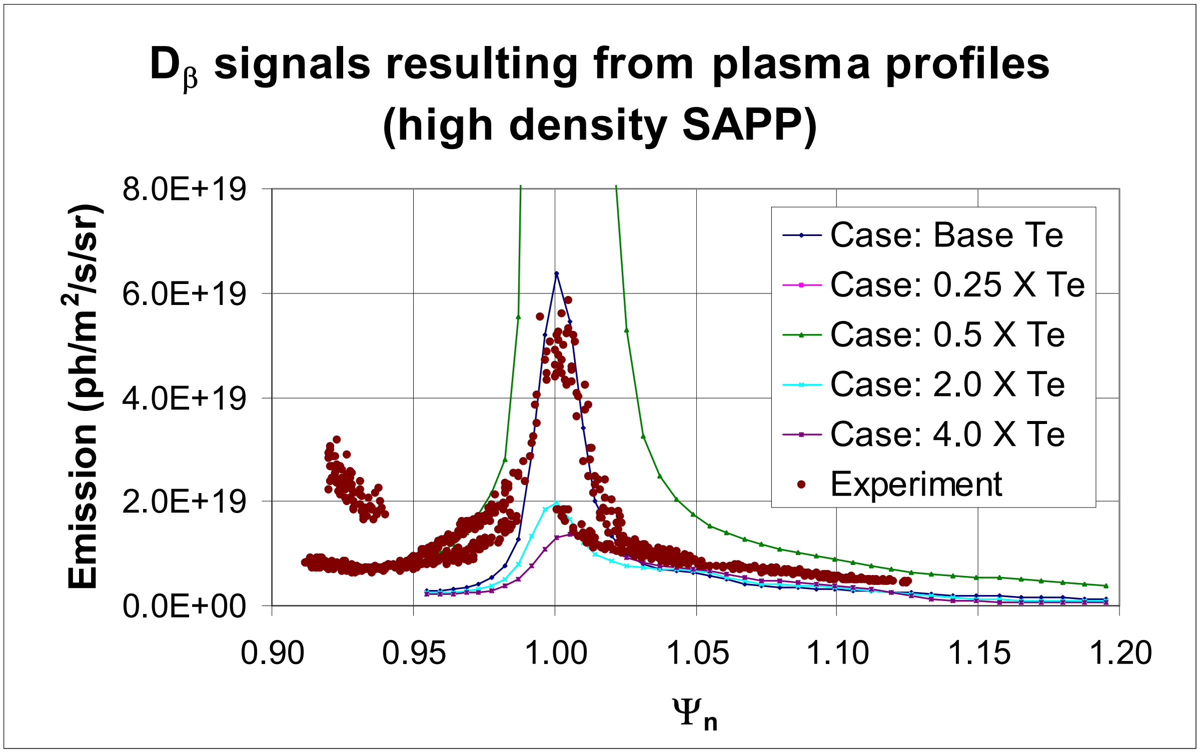

D_β signals resulting from plasma profiles
(high density SAPP)
Emission (ph/m^2/s/sr)
1.2E+22
1.0E+22
8.0E+21
6.0E+21
4.0E+21
2.0E+21
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψ_n
Case: Base Te
Case: 0.25 X Te
Case: 0.5 X Te
Case: 2.0 X Te
Case: 4.0 X Te
Experiment


D_γ signals resulting from plasma profiles
(high density SAPP)
Emission (ph/m^2/s/sr)
3.0E+21
2.5E+21
2.0E+21
1.5E+21
1.0E+21
5.0E+20
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψ_n
Case: Base Te
Case: 0.25 X Te
Case: 0.5 X Te
Case: 2.0 X Te
Case: 4.0 X Te
Experiment

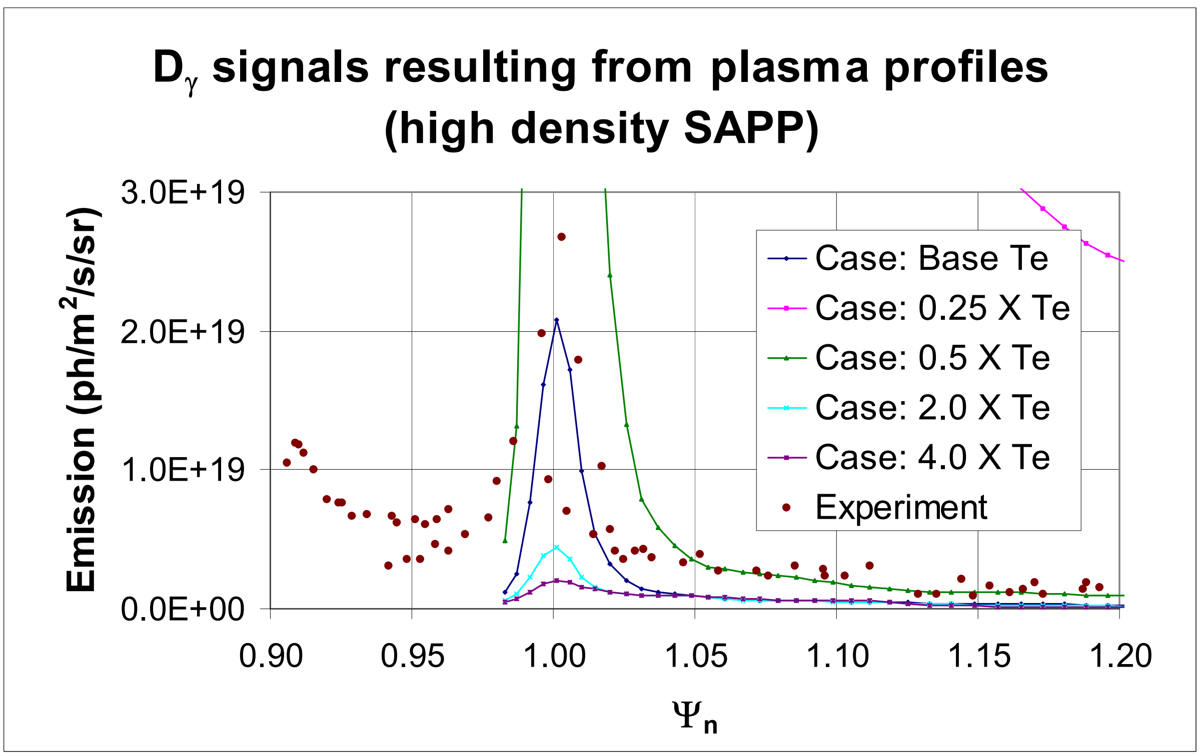
Emissions at High Density with Revised Scaling

- Only the "base" case result is close to the experimental observations. All other results differ by a factor of two and usually much larger.





Dβ signals resulting from plasma profiles
(high density SAPP)
Emission (ph/m2/s/sr)
8.0E+19
6.0E+19
4.0E+19
2.0E+19
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψn
Case: Base Te
Case: 0.25 X Te
Case: 0.5 X Te
Case: 2.0 X Te
Case: 4.0 X Te
Experiment



Dγ signals resulting from plasma profiles
(high density SAPP)
Emission (ph/m2/s/sr)
3.0E+19
2.0E+19
1.0E+19
0.0E+00
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Ψn
Case: Base Te
Case: 0.25 X Te
Case: 0.5 X Te
Case: 2.0 X Te
Case: 4.0 X Te
Experiment

Results from Varying Plasma Conditions

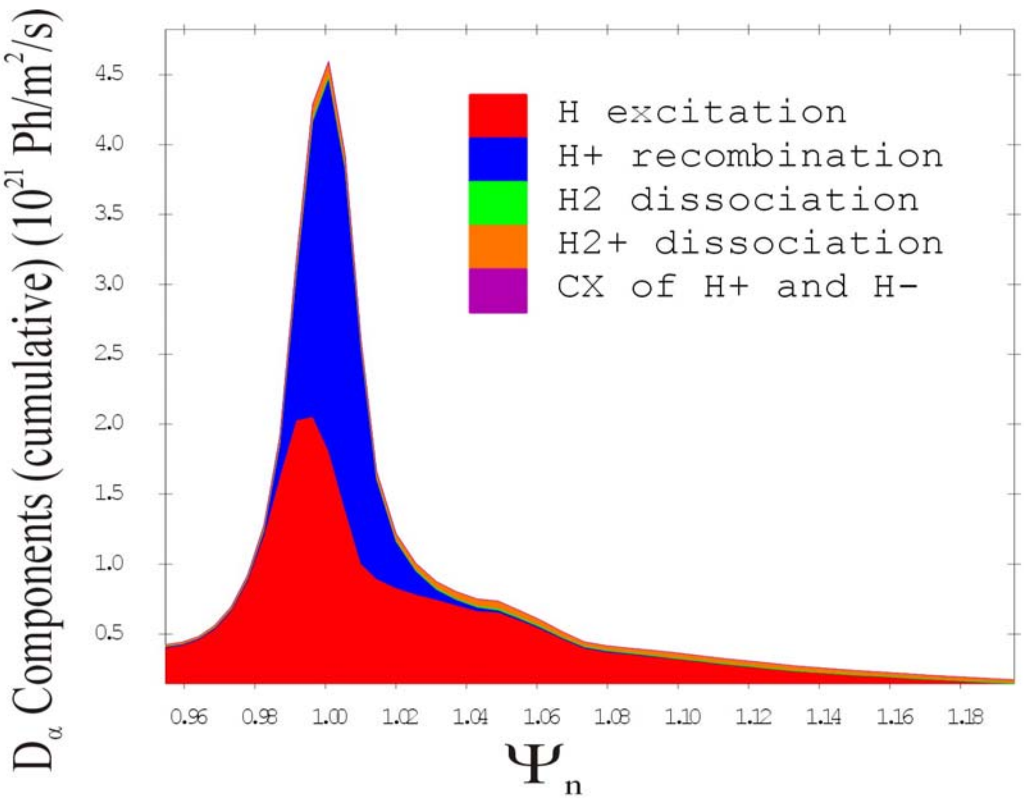
- The set of steady state plasma conditions for each density described in the previous figures cover a large range of density and temperature.
- The emission for the low and medium density SAPP plasmas is affected very little by the large changes in the background plasma conditions.
- The effect of such changes in the background plasma for the high density case is very large.

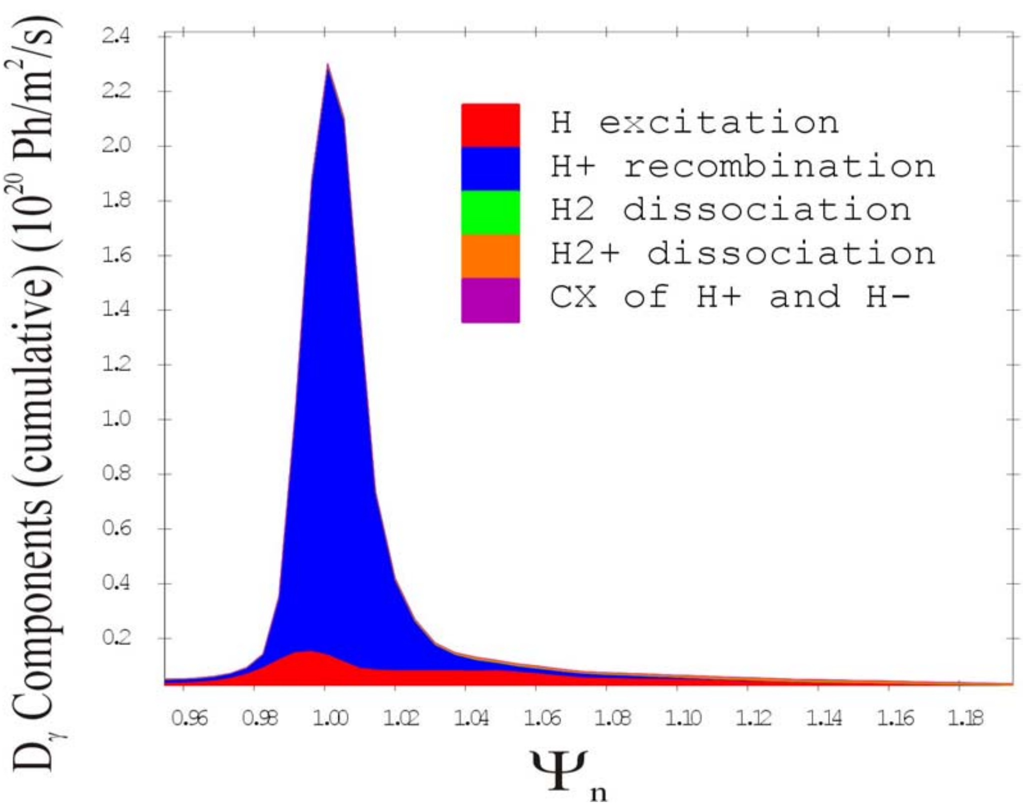
Why is the High Density case different?

Several observations for the high density SAPP case lead to the conclusion that the plasma is stable and **detached**, or nearly detached (‘roll-over’ regime), in a small region near the outer strike point.

- The DTS measurements show the low temperatures and high densities indicative of detachment for the location nearest the target.
- The emission calculated for the “base” high density SAPP case which match the experimental observations has a large component due to recombination emission.

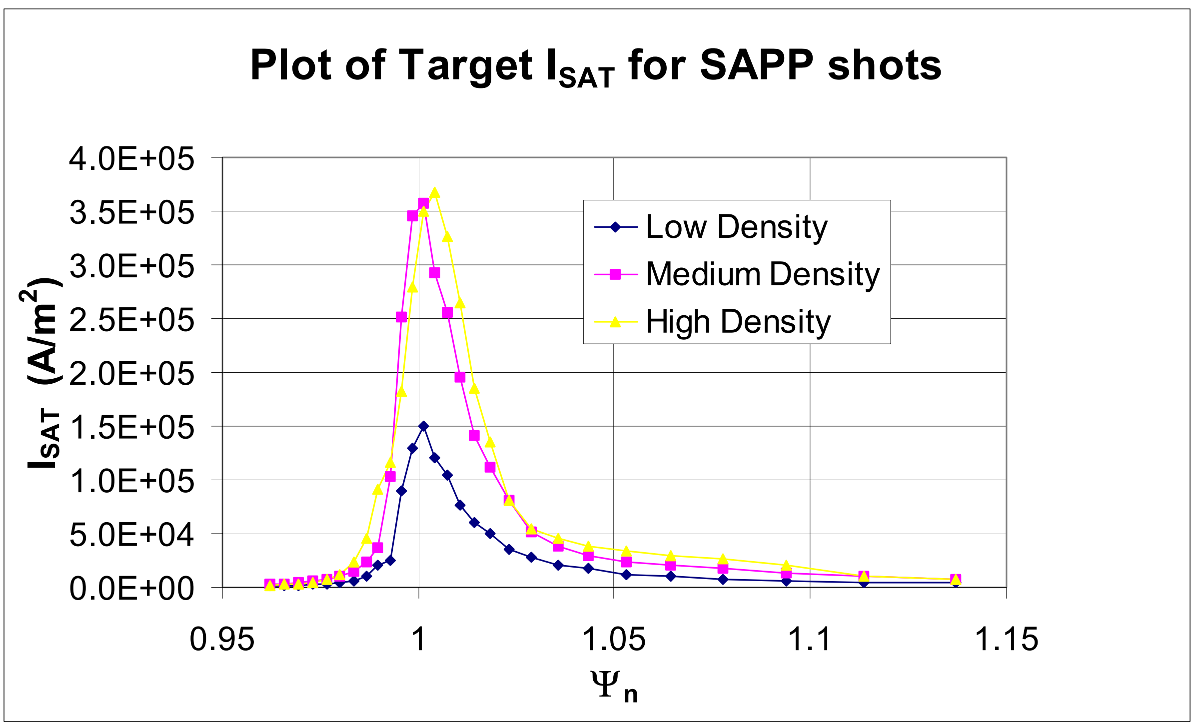
Calculated Emission is Largely Due to Recombination





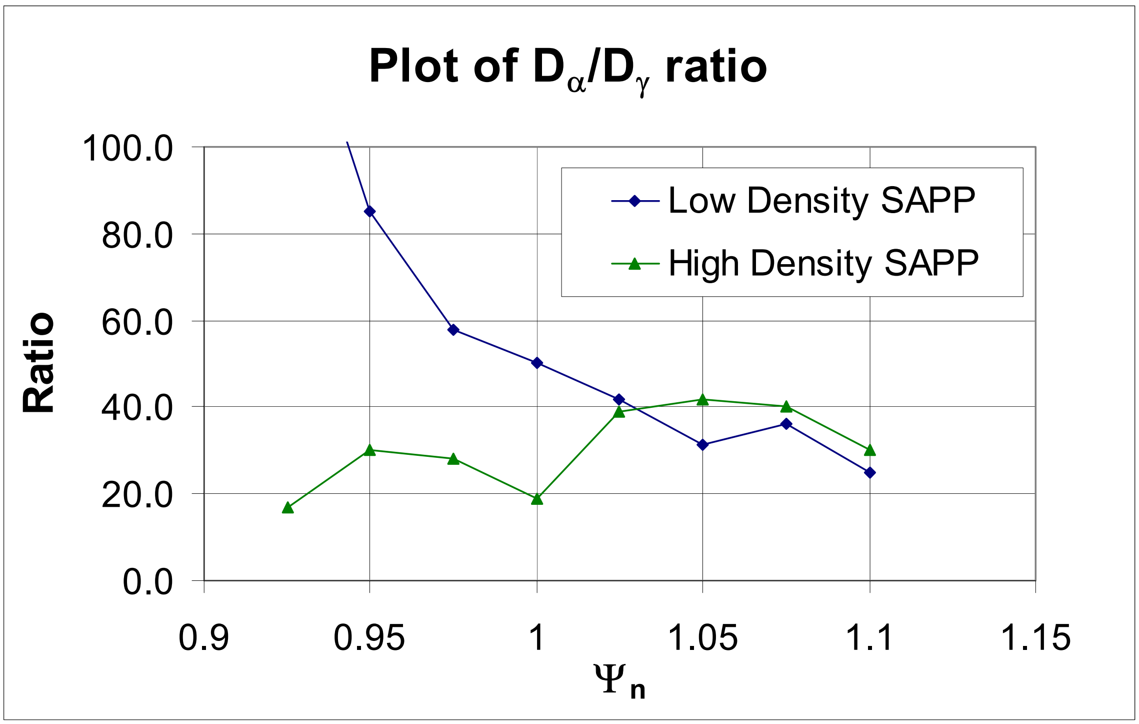
Langmuir Probe I_{sat} does not Increase

- The Langmuir probe I_{sat} measured for the high density SAPP is almost the same as the medium density SAPP (a possible indication of the "roll-over" regime) yet the D_α signal for the high density SAPP is much larger than that for the medium density. If the difference in signal is not due to the influx of hydrogen then it must be due to the plasma conditions in the near target region.



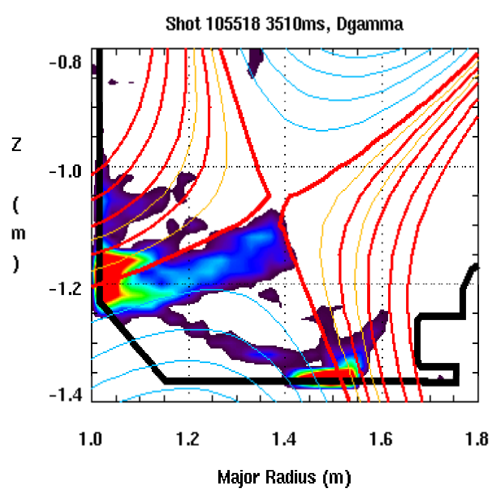
D_α/D_γ Ratio is Indicative of Detachment

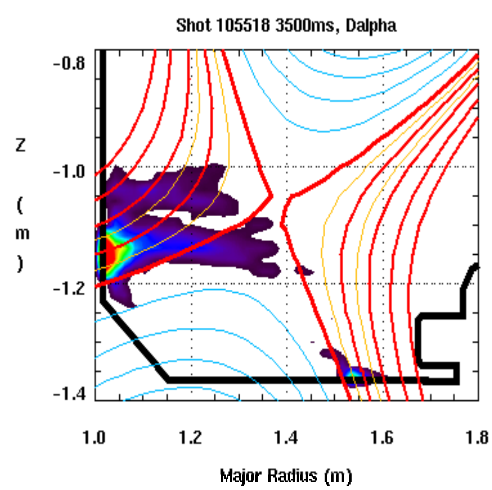
- A plot of the D_α/D_γ ratio for the SAPP shots shows that there is a significant dip of this ratio in the outer strike point region for the high density SAPP – a clear sign of the recombination radiation associated with detachment.



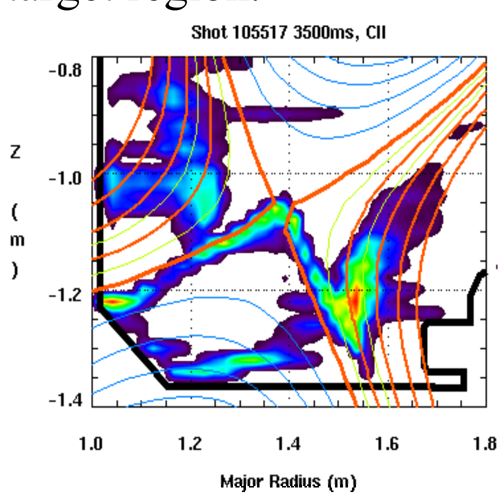
Tangential Cameras Indicate Detachment

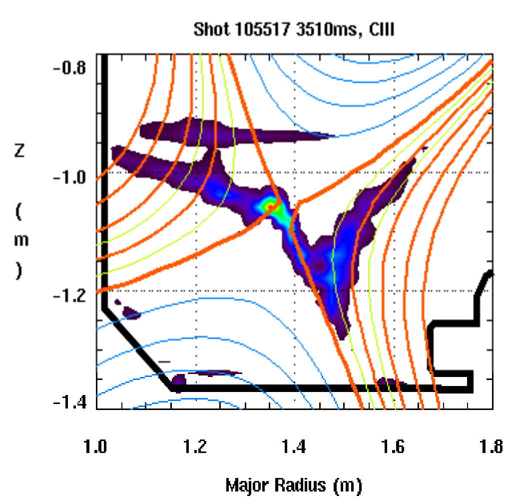
- Tangential camera image reconstructions show a significant D_γ emission region near the outer strike point. Although not intensity calibrated, these images show D_γ and D_α emissions at the outer target that are comparable with the inner target regions. The inner target is almost certainly detached in the high density case and these images help confirm that the outer target is also detached at the strike point.





- In addition, the CII and CIII emission patterns tend to be indicative of temperatures less than 5eV in the near target region.



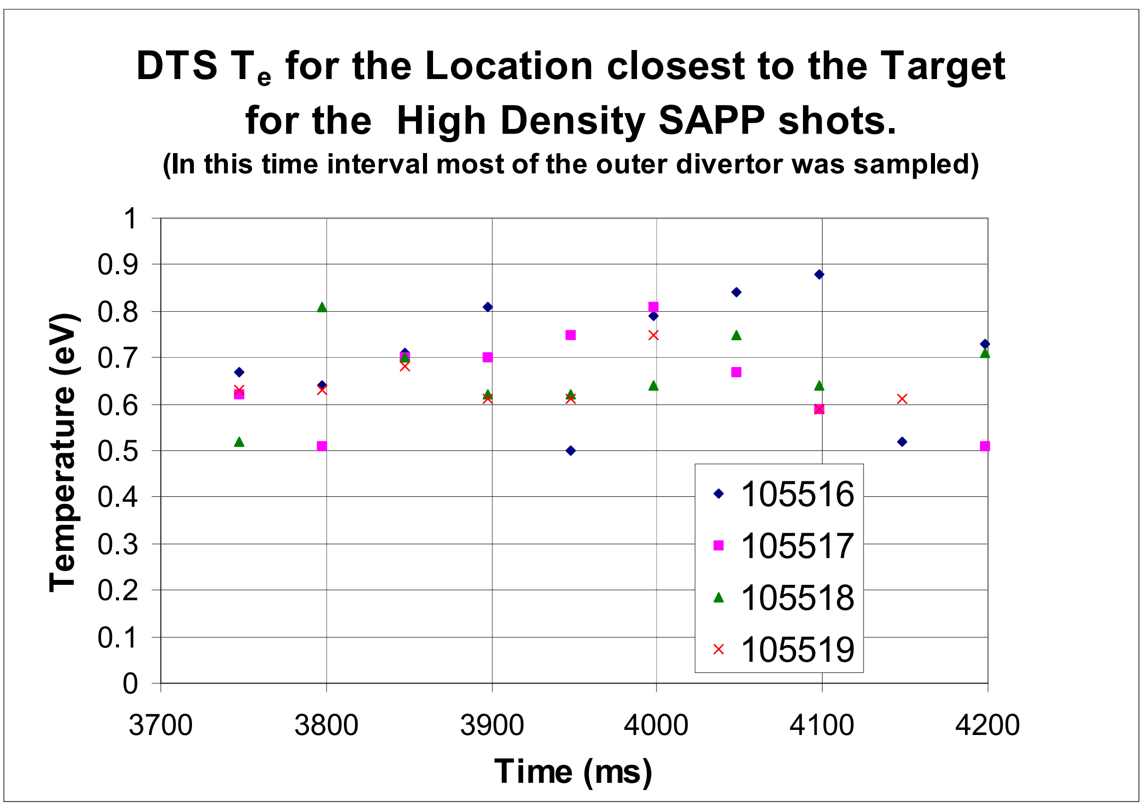


Discussions and Conclusions

- The measurements made by DTS, Langmuir probe I_{sat}, and spectroscopic diagnostics are quite consistent in terms of time-average behaviour over the range of densities examined in the SAPP shots. In particular, the values measured by DTS are consistent with the spectroscopic results.
- The highest density shots for SAPP are detached or nearly detached at the outer strike point. This region of detachment, although spatially localized, is stable since the measurements shot to shot and over time within each shot were stable and reproducible.
- Large changes assumed in the background conditions of attached plasmas have very little effect on the calculated spectroscopic measurements. It is therefore difficult to use these cases to make a definitive statement about the DTS T_e and the Langmuir probe T_e.
- Small background plasma changes in the case of detached plasmas have very large effects on emission and presumably on other atomic processes. The highest density SAPP case indicates that the DTS system is returning valid n_e and T_e data even for such extreme conditions and that there is only moderate fluctuation in these measurements from shot to shot.
- The DIII-D SAPP plasmas, even for the highest density, where the outer divertor near the strike point is cold and detached, are characterized by quantitatively interpretable atomic physics based on the time-averaged

Divertor Thomson Scattering and target Langmuir probe I_{sat} measurements.

- The results here, based on the time averaged n_e and T_e from DTS and I_{sat}, agree quite well with the time averaged emission, even in the case of detachment. However, this is not necessarily a general result. The DTS data taken closest to the target for the high density case shows only modest variation or fluctuation. The data in the next figure was taken over a sample period of 500ms which, with sweeping, covers about 10cm of the outer divertor target. It may be that these SAPP detached plasmas are unusually quiescent. For the hotter cases, the sensitivity study shows that plasma fluctuation would have only a limited effect on the hydrogenic emissions.



Summary

The idea behind SAPP is to arrange for a series of discharges in which the divertor plasma conditions are sufficiently simple (i.e. no ELMs or other extreme phenomena) that most or all of the edge measurements can be included in comprehensive interpretive undertakings aimed at identifying the controlling physics processes in the edge.

Three SAPP density conditions have been studied so far. The lowest density set (at $\bar{n}_e$ ~$2.5 \times 10^{19} m^{-3}$) was assessed earlier [PSI2002] and was found to be a satisfactory test plasma for pursuing the study of edge issues such as chemical sputtering.

In this poster, we have looked at the conditions at three densities with particular attention paid to the higher density discharges at $3.5 \times 10^{19} m^{-3}$ and $4.5 \times 10^{19} m^{-3}$. At the highest density, the outer divertor, where the diagnostics are concentrated, is detached or nearly so.

Detachment is a most important divertor condition to be able to interpret and understand. There are, however, a number of concerns about the consistency and interpretability of even the most basic divertor diagnostics (DTS, target probes, hydrogenic spectroscopic line emissions) under these conditions.

Here, the consistency amongst the DTS, probe I_{sat} and deuterium line emissions was investigated. Since emission (along with most other atomic physics processes) is a non-linear function of n_e and T_e, particularly for detached plasma conditions, and since edge fluctuation levels can be very high, it is not assured that there is very much connection between time-averaged emission and time-averaged n_e and T_e. If there is no simple connection then interpretive undertakings are likely to be very difficult.

It was found here, however, that even for detachment these diagnostics are rather consistent, based on the time-averaged measurements, therefore indicating that these SAPP plasmas are useful test conditions for studies aimed at identifying and quantifying the controlling physics of the edge.