LIDAR TS for ITER Core Plasma,
Part 2: Simultaneous Two Wavelength LIDAR TS

Chris Gowersa, Per Nielsen, and Hans Salzmann

E-mail: chris.gowers@which.net

Introduction

We have shown recently, and in more detail at this conference (Salzmann et al) that the LIDAR approach to ITER core TS measurements requires

1. only two mirrors in the inaccessible port plug area of the machine, leading to
2. simplified and robust point and shoot alignment
3. lower risk of mirror damage by plasma contamination
4. much simpler absolute density calibration

when compared with the awkward and vulnerable optical geometry of the conventional imaging core TS system, currently being adopted by ITER. In that system at least twice as many optical components are used in the port plug area, several of which are very close to the plasma surface and therefore more prone to damage and contamination.

Here we have extended the simulation code to include launching ***two laser pulses, of different wavelengths, simultaneously in LIDAR geometry***.

Aim - to broaden choice of lasers available for the diagnostic.

In the code two 300 ps laser pulses of different wavelengths, from an Nd:YAG laser (fundamental @1064 nm and 2nd harmonic @ 532 nm) are launched through the plasma simultaneously.

The T_e and n_e profiles are deduced in the usual way but from the resulting *combined* scattered signals in the different spectral channels of the **single** spectrometer.

The spectral response and quantum efficiencies of the detectors used in the simulation are taken from catalogue data for commercially available Hamamatsu MCP-PMTs (types R3809U-61/-63-64). The response times and gateability of this type of photomultiplier have already been demonstrated in the JET LIDAR system, and give sufficient spatial resolution to meet the ITER specification. They also tolerate the stray laser light levels encountered in LIDAR geometry.

Here we present the new simulation results from the code.

These results demonstrate that when the detectors are combined with the two laser wavelength approach, the full range of the specified ITER core plasma T_e and n_e can be measured with sufficient accuracy and spatial resolution.

So, with commercially available detectors and a relatively simple modification of a Nd:YAG laser similar to that currently being used in the design of the conventional ITER core TS design, the ITER requirements can be met ***but with somewhat lower laser pulse energies***.

The simulation program – the spectrometer

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Scattering Angle: 180.0
Laser Wavel.:1064. 532. nm
Energies    :  2.0  0.5 Joule
Scatt. length: 7.0 cm
Density:    1.0 E19 m-3
Transmission (%):  20.0
F/#   10.0
Noise Figure:    2.0
NEP (phots/gate)    5.0
Backg(p.e./nm@1000nm)62.3*qe
```

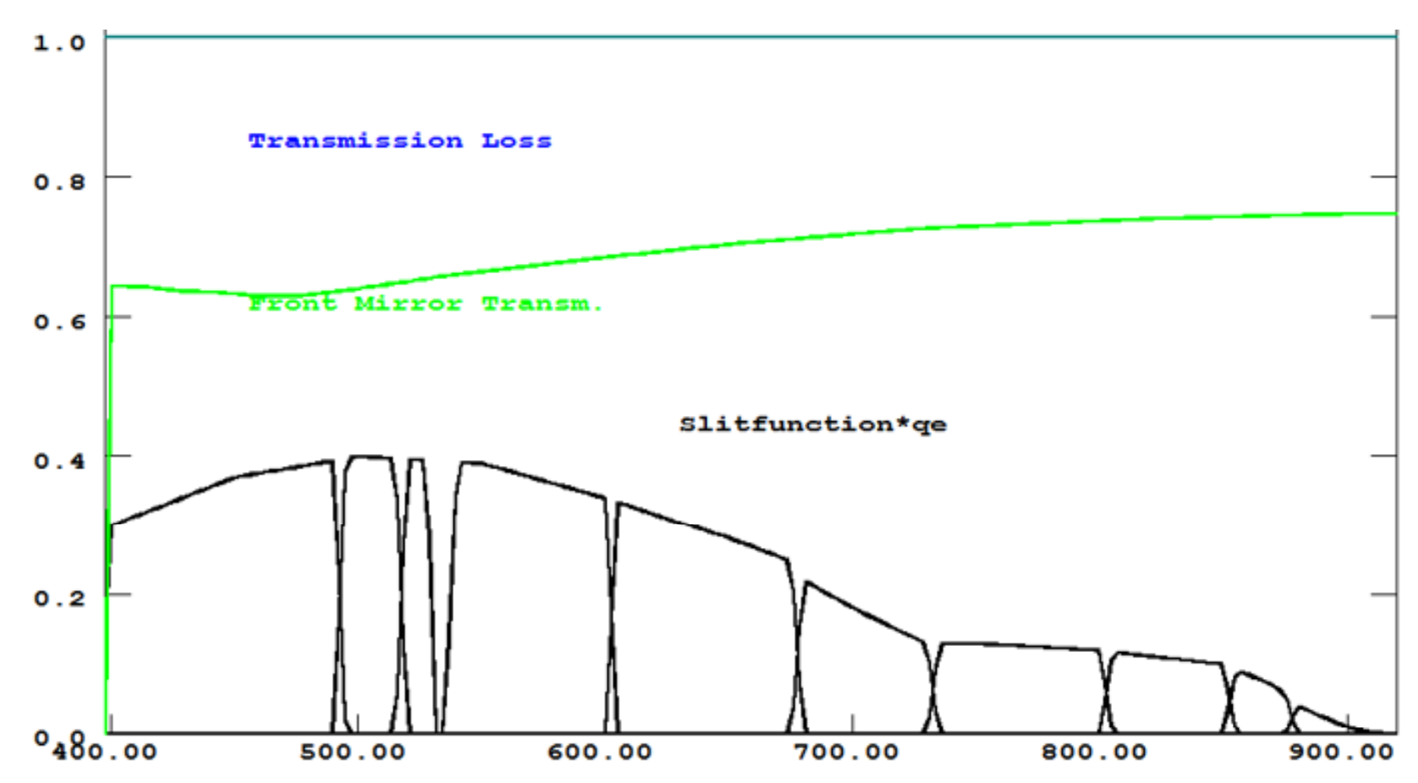

Figure 1: Typical channel distribution of spectrometer. Amplitude given by *qe* of associated detector type. The small gap in the spectral coverage is at 532 nm to aid stray light suppression from the 2nd harmonic pulse. The spacing and width of channels to the left give the low temperature capability of the spectrometer. The green curve is the reflection of front mirrors

Simulation - Region of no Vignetting

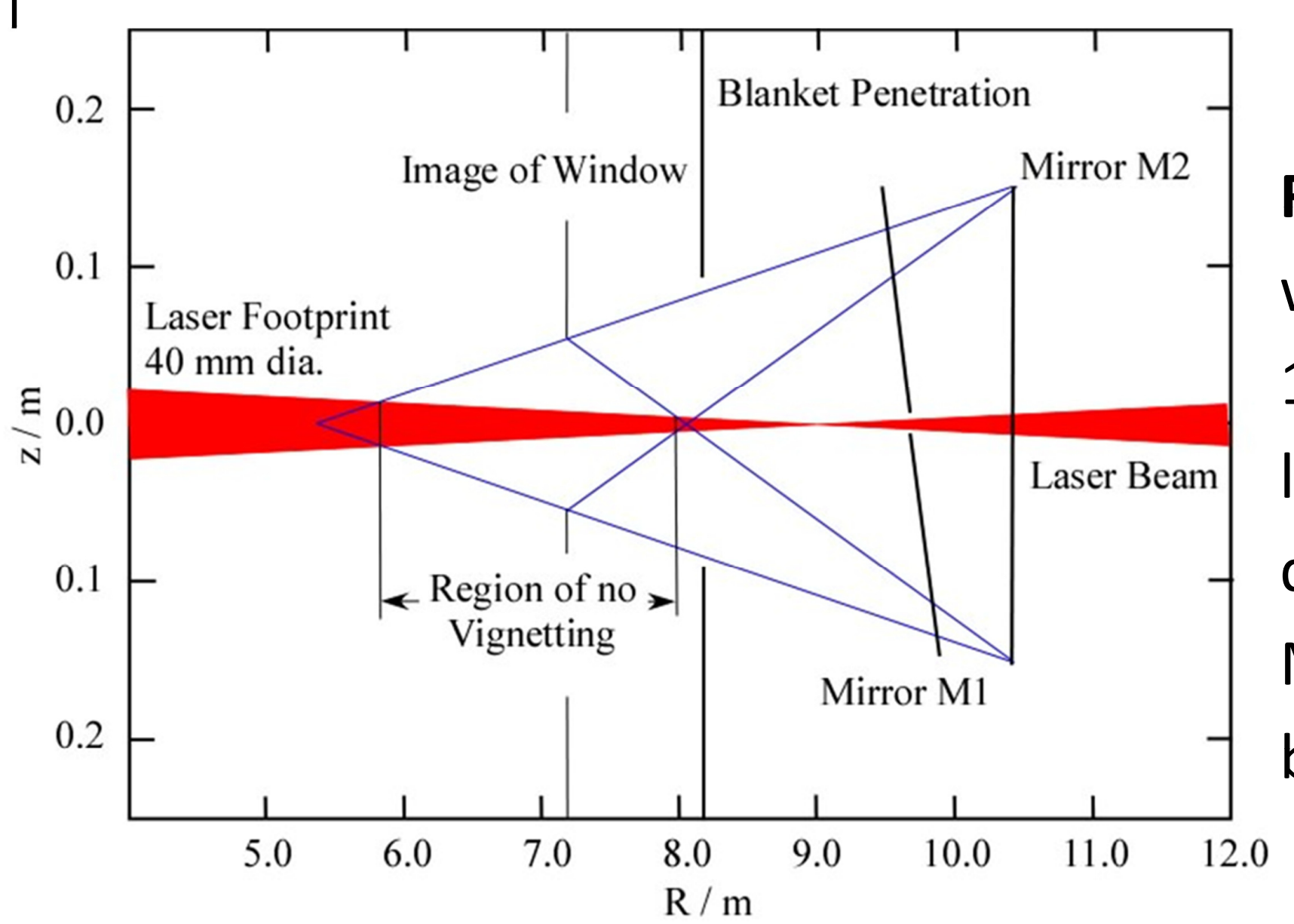

Figure 1: This graph illustrates a solution where we have chosen D/F = 10 mm and M2 located at 10.45 m with a diameter of 300 mm. The slanted line at 9.7 m illustrates that the collected light is deflected at this location by the slightly oversized M1. A small hole in this mirror allows the laser beam to enter the plasma.

Some details of the simulation code

The fitting routine in the program is basically the same as the routine used at JET for analysing LIDAR experimental data until at least 2004.

For calculating the signals in the spectral channels, we use the same spectral density function as used at JET, including the depolarization term. A comparison of the calculated spectrum with that of Beausang and Prunty shows perfect agreement.

The key difference between our approach and that of other authors using two laser beams in a TS system, is that here, we use two **simultaneous** laser beams with individual wavelengths and energies. Overall, we find very good results are obtained when we assume a Nd:YAG laser source, emitting 300 ps pulses at 1064 nm and 532 nm, with typically energies of 2 J and 0.5 J respectively.

The transmission of the collection system uses the specular reflectivity of either Rh or Mo for the materials of the two first mirrors inside the port plug. The reflectivity is calculated for s-polarization and the respective angles of incidence at the two mirrors. The transmission of the remaining optics in both laser beam path and the collection system is set to a total of 20%.

In the current calculations, we have used the quantum efficiency (qe) of three commercially available detectors from Hamamatsu, (R3809U-61/63/64) with a noise figure of 2. These detectors all have a photocathode diameter of 10 mm. Fig. 1 shows a typical channel distribution of the single 10 channel spectrometer. For each channel a specific detector is chosen, the amplitude of the channels is the quantum efficiency of the respective detectors. Also shown in the figure is the product transmission of the two front Rh mirrors in this case (green curve).

Simulation – Results T_{eo} from 2 – 40 keV;

Figures 3-6 show at the left the "raw signals", i.e. the calculated detector signals with the photo-electron statistics included. The figures to the right show the input data and the fitted single shot profiles with error bars.

In Figure 7 we compare a high density case with the "normal" minimum density used in most the other cases presented. Note the improved accuracy at high density. In figure 8 we have investigated restricting the spectral range of the spectrometer should excessive line radiation be a problem.

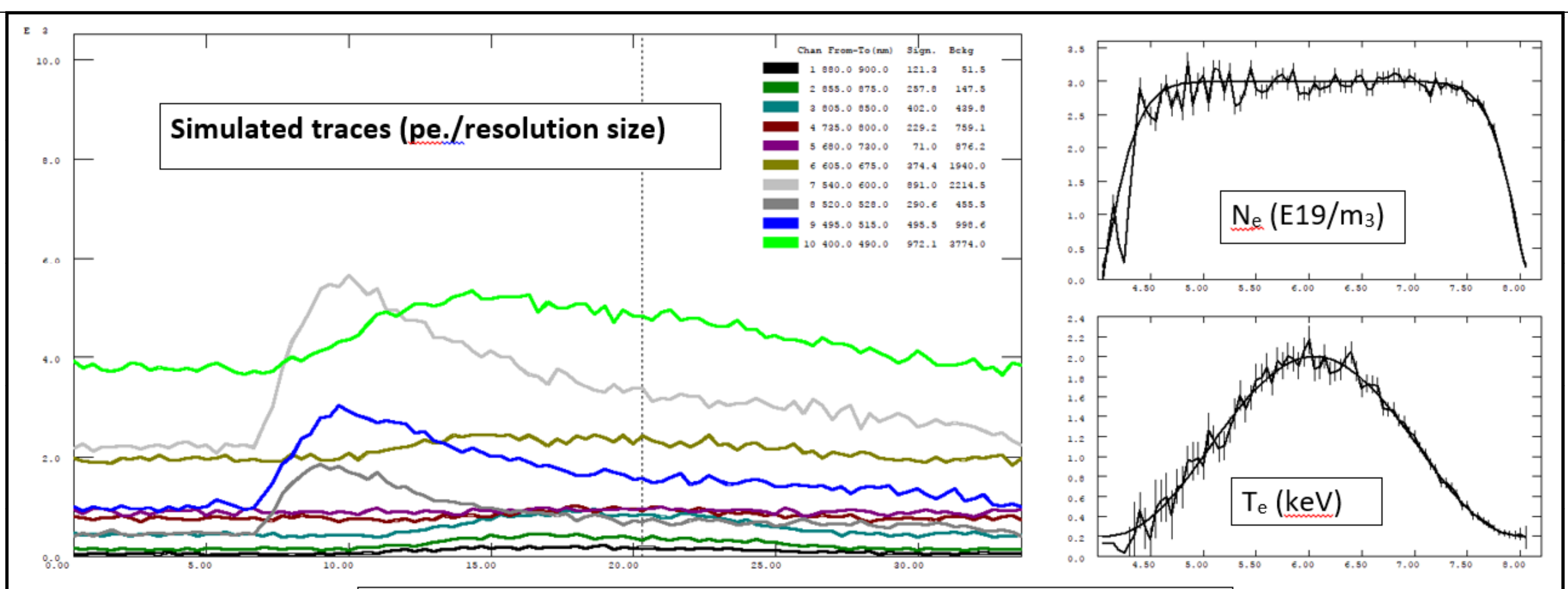

Figure 3 T_{eo} = 2 keV; n_{eo} = 3.0x10^{19}m^{-3}; 2 J_{1064}; 0.5 J $_{532}$

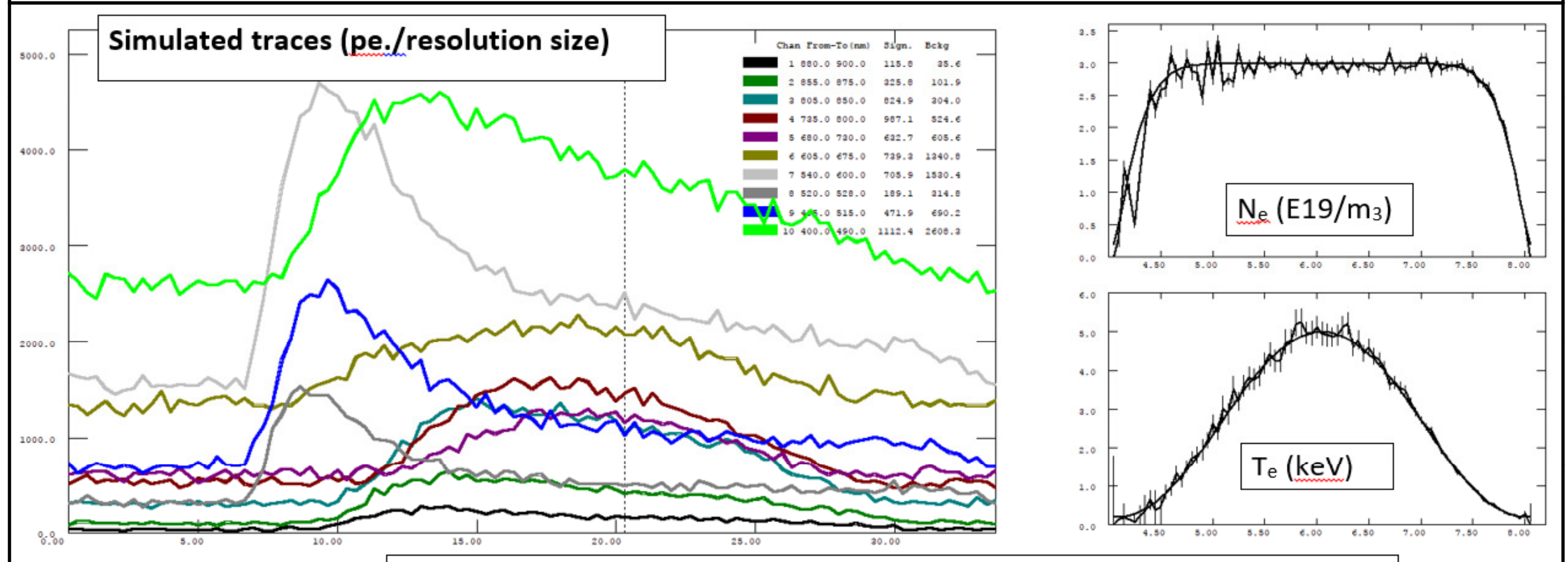

Figure 4 T_{eo} = 5 keV; n_{eo} = 3.0x10^{19}m^{-3}; 2 J_{1064}; 0.5 J $_{532}$

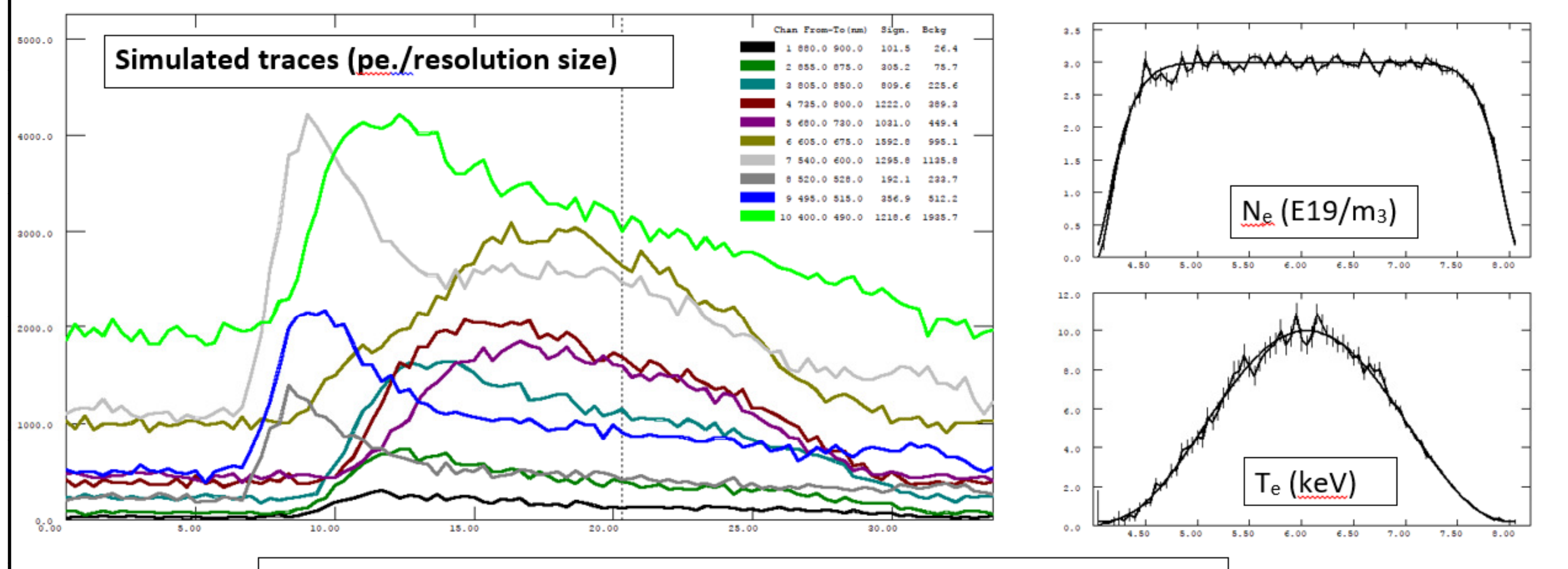

Figure 5 T_{eo} = 10 keV; n_{eo} = 3.0x10^{19}m^{-3}; 2 J_{1064}; 0.5 J $_{532}$

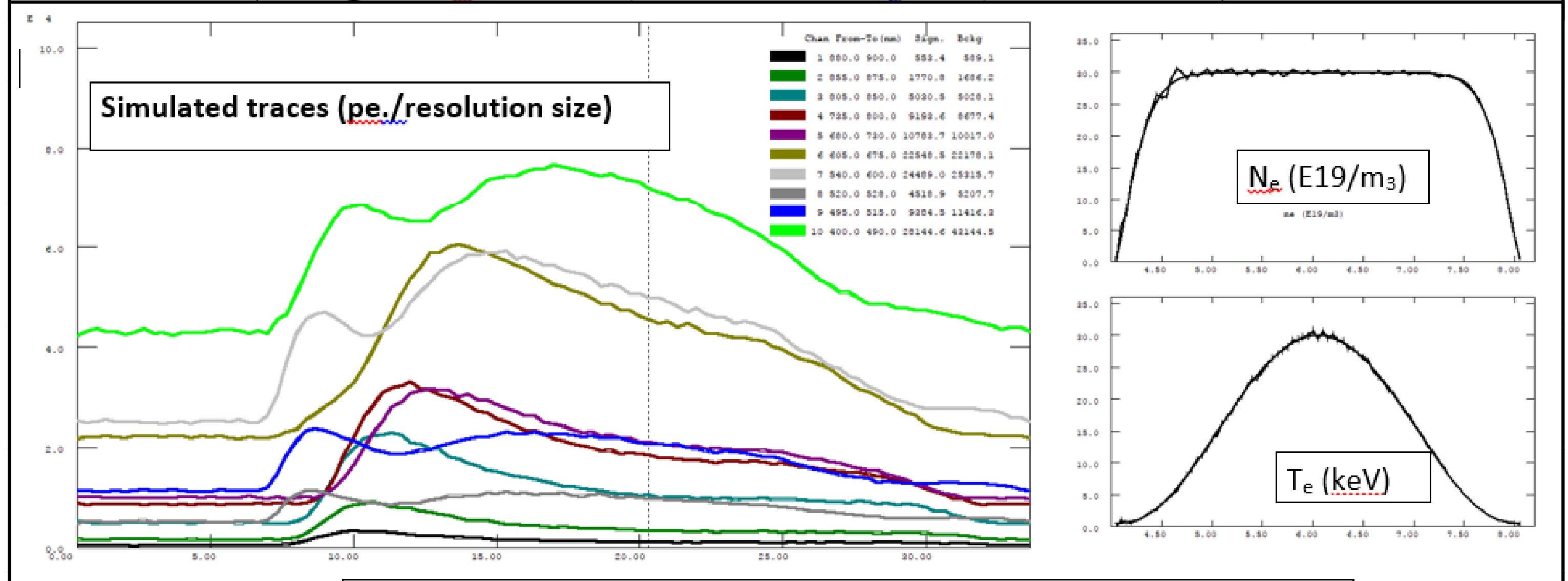

Figure 6 shows plasma light signals at very high density:
T_{eo} = 30 keV; n_{eo} = 30.0x10^{19}m^{-3}; 2 J_{1064}; 0.5 J $_{532}$

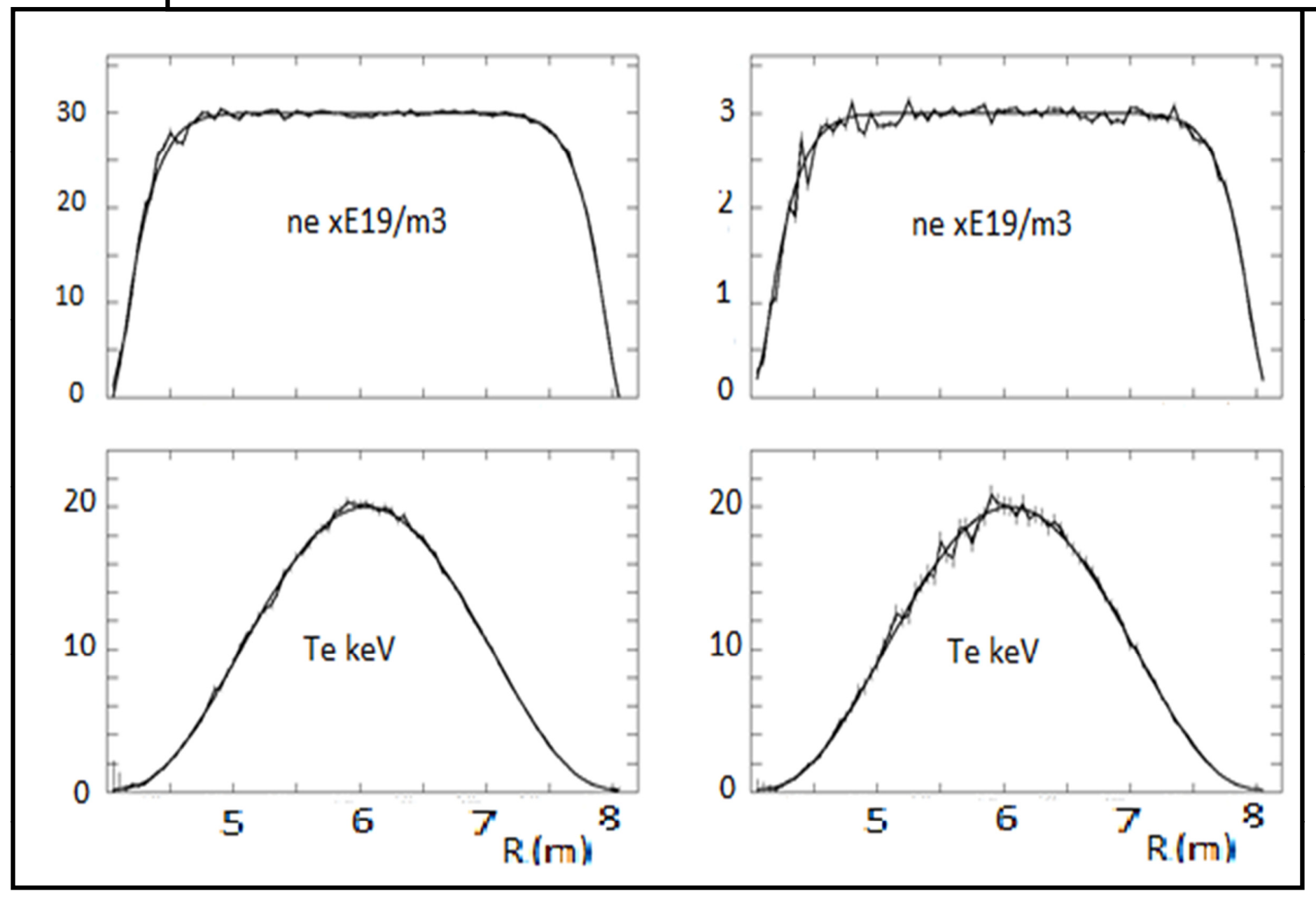

Figure 7(i) High density T_{eo} = 20 keV; n_{eo} = **30x10^{19}**m^{-3}; and (ii) T_{eo} = 20 keV; n_{eo} = 3x10^{19}m^{-3} for comparison. Note in (i) as expected, the much higher accuracy of the measurements at high density

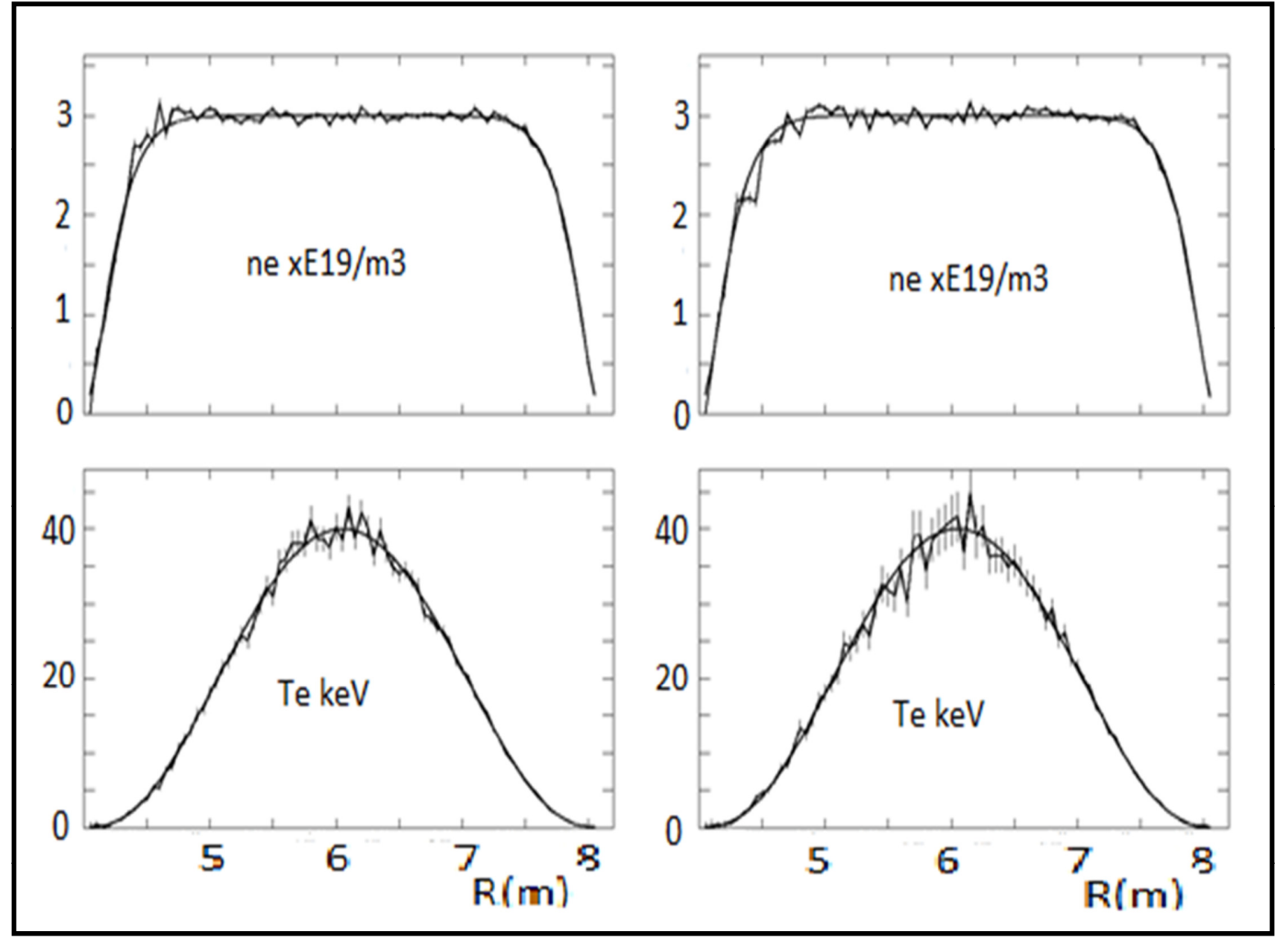

Figure 8(i) T_{eo} = 40 keV; n_{eo} = 3x10^{19}m^{-3}; (ii) T_{eo} = 40 keV; n_{eo} = 3x10^{19}m^{-3} 395 -495nm channel removed. Note in (ii) slightly larger error bars but still within specified accuracy.

Conclusions

We have shown that, based on our simulations

1. A LIDAR TS system where two 300 ps laser pulses of different laser wavelength are launched simultaneously through the ITER plasma, that core T_e and n_e profile measurements can be made which meet the required accuracy over the specified range.
2. We point out that the commercially available Hamamatsu MCP-PMTs used in the simulations have been successfully tested in the JET LIDAR system.
3. Only modest laser energies of 2 J and 0.5 J at the Nd:YAG fundamental (1064 nm) and its 2nd harmonic (532 nm) are required

By setting the lower limit of the spectrometer to ~500 nm, we have also shown that sufficiently accurate measurements, even at the highest T_{eo}, can still be made if issues associated with excessive line radiation between 400 nm and 500 nm should become a problem.

Although this LIDAR system has been optimised to make the most accurate measurements from the plasma centre to near the outer plasma edge, it will also still make measurements on the high field side almost to the inner wall, with similar accuracies. This is in contrast to the conventional TS system design, currently being pursued by ITER, which cannot access the high field side at all.