26th EPS Conf. on Contr. Fusion and Plasma Physics, Maastricht, 14 - 18 June 1999 ECA Vol.23J (1999) 1633 - 1636

Density measurements with combined Li-beam diagnostics and microwave reflectometry during advanced tokamak operation on ASDEX Upgrade

I. Nunes[1], M. Manso[1], P.Varela[1], F.Serra[1], A. Silva[1], F.Silva[1], J.Schweinzer[2]
[1] *Associação EURATOM/IST, Centro de Fusão Nuclear, Instituto Superior Técnico,*
1096 Lisboa Codex, Portugal
[2] *Max-Planck-Institut für Plasmaphysik, EURATOM Association,*
D-85748 Garching, Germany
R.Brandenburg[3], F.Aumayr[3], HP.Winter[3]
[3] *Institut für Allgemeine Physik, TU Wien, Association EURATOM-OEAW,*
A-1040 Wien, Austria

1. Introduction

The purpose of this paper is to discuss the combination of two diagnostics for edge density measurements on ASDEX Upgrade: Reflectometry is suited for measuring the plasma density with very high temporal resolution which gives access to fast phenomena such as fluctuations. However, it lacks information from the low density edge plasma which is crucial for the correct evaluation of the edge gradients. Fast neutral Li beam diagnostics is a standard method for measuring the density in the outer edge region of ASDEX Upgrade.

Experimental setup of reflectometry

In ASDEX Upgrade the broadband FM reflectometry diagnostic has twelve channels, probing simultaneously the high-field (HFS) and low-field (LFS) sides of the plasma with ultrafast sweeping (20-100 µs). The O-mode frequencies (16-70 GHz) are reflected from densities ~0.4 $\times 10^{19} < n_e < 7\times 10^{19}\mathrm{m}^{-3}$, and X-mode (33-70 GHz) is used for the scrape-off layer at LFS. A channel dedicated to operating in fixed frequency (range 33-50 GHz) provides during the whole discharge a signal to monitor continuously the level of density fluctuations at selected density layers. The density profiles are obtained with a data analysis method where the time versus (beat) frequency distribution of the energy of the reflected signals is computed; this gives the group delay versus frequency, corresponding to the plasma profile and also the zones to where the signal energy has been displaced (scattered) by fluctuations [1].

For the initialisation of the density profiles two methods are routinely used: information from the X mode when available or numerical estimation based on the group delay gradient.

Short description of Li beam diagnostics

In the outer plasma edge the plasma electron density profile is obtained by fast Li beam impact excitation spectroscopy (Li-IXS). This diagnostic method is based on the observation of LiI radiation (670.8 nm) from Li atoms injected with 35 keV energy into the plasma. Emission profiles with high spatial resolution can be converted into the corresponding electron density profiles for line integrated densities of up to $\int n dx \approx 10^{18}\mathrm{m}^{-2}$. The determination of electron densities from Li-IXS raw data is based on a system of differential equations representing a detailed modelling of the Li beam which includes all possible transition processes within the Li(nl), $n \leq 4$, and Li$^+$ levels [2,3]. A detailed description of the experimental setup is given in [4]. The temporal resolution of the Li beam is restricted to a few *ms* due to signal statistics.

Thus, rapid phenomena such as density fluctuations are not accessible unless special modifications are applied.

2. Combined Li beam and Reflectometry diagnostics

With O mode reflectometry signals densities from 0.4×10^{19} m^{-3} to 7×10^{19} m^{-3} can be measured, which means that information concerning the low density region of $n_e < 0.4\times10^{19}$ m^{-3} is required for an accurate reconstruction of the profile. One possiblity is the X mode, measuring the edge from zero density to $n_e \approx 0.4\times10^{19}$ m^{-3}; however, the V band (50–70 GHz) is presently not acquiring. The X mode cut-off depends on the magnetic field [$f_{ce}(a) = eB/2\pi m_e$]; thus, for a magnetic field of 2.4 T the first reflected frequency is about 52 GHz, which means that in such cases it is not possible to get information from the X mode. Since the Li beam measures from zero density, it can supply relevant data for reflectometry edge density profiles below $n_e < 0.4\times10^{19}$ m^{-3}. The Li beam information is used to complement the curves of group delay of reflectometry signals due to plasma reflections. To obtain the group delay from Li beam profiles, the principle of reflectometry was applied: emitting an electromagnetic wave, the group delay is obtained by measuring the reflection of the wave at each density layer. We must note that the electron density profile from Li beam has been averaged over 5 ms and that the profiles from reflectometry have been averaged over less than 1 ms for this study. Reflectometry acquires several bursts spaced by a few ms with each burst consisting of 16 sweeps at 20 µs per sweep.

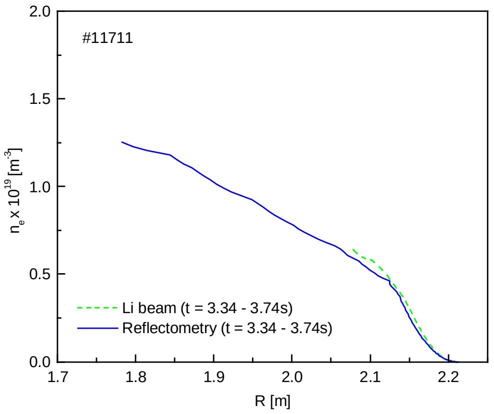


Fig 1 *Comparison between reflectometry with numerical initialisation and Li beam profiles for shot #11711, t = 3.744s*

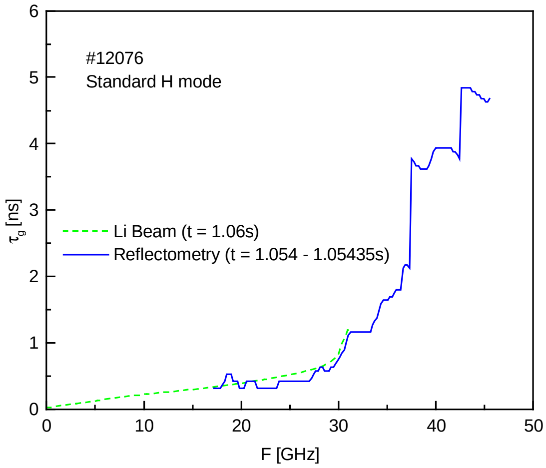


Fig. 2: *Group delays from reflectometry and inversion of Li beam density profile for a standard H mode shot, t = 1.054s.*

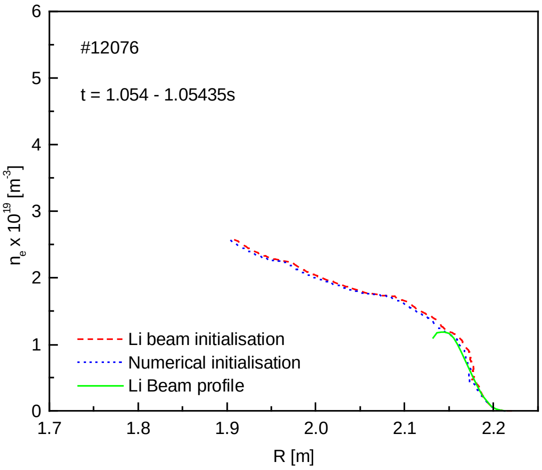
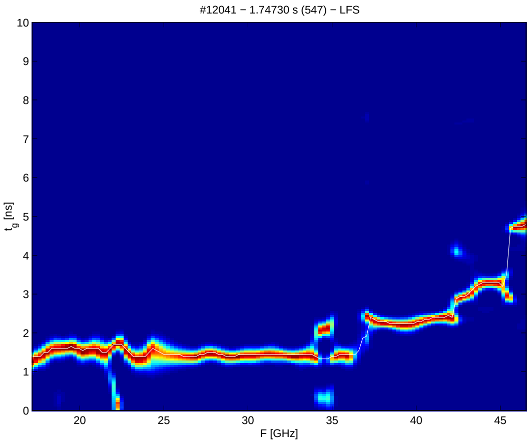


Fig. 3: *Profiles obtained with numerical and Li beam initialisation compared to Li beam result.*

Fig. 1 shows density profiles from reflectometry and Li beam diagnostics for an Internal Transport Barrier (ITB) L-mode shot. Both profiles agree at the edge. Fig. 2 shows the group delay of reflectometry signals for a standard H-mode shot and the group delay obtained by inversion of the Li beam profile. Converting the group delay by Abel-inversion, we get the reconstructed profile. The density profiles obtained by reflectometry with numerical and Li beam initialisation are presented in fig. 3 which also shows the original Li beam result.

3. Analysis of improved confinement scenarios

At the very edge, the K band is often perturbed by fluctuations, which means a loss of signal. Fig. 4 shows how the Li beam data can help to initialise the reflectometry density profile in an H-mode shot with an ITB, where the K band was strongly perturbed. This figure shows clearly that the errors for the reconstruction of the profile by initialisation with numerical estimation are not negligible. In this shot there was also no X mode data. The next figures show two examples of different scenarios of operation. Figs. 5 and 6 show an ITB L-mode shot, where



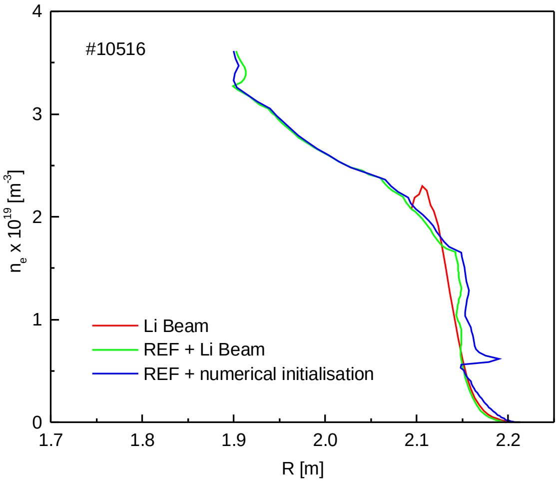


Fig. 4: *Density profile where the K band was strongly perturbed. Initialisation was made with Li beam information.*

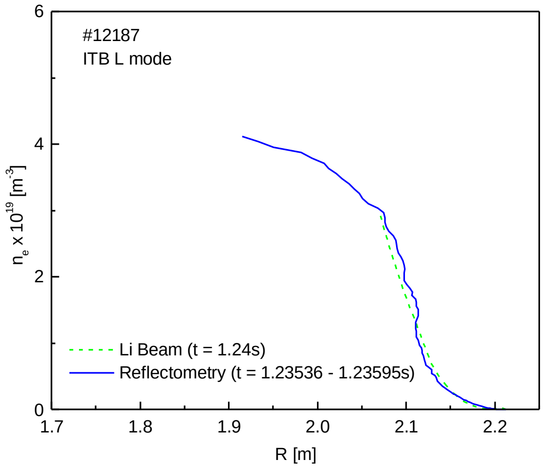


Fig. 5: *Density profiles from reflectometry and Li beam from a ITB L mode shot.*

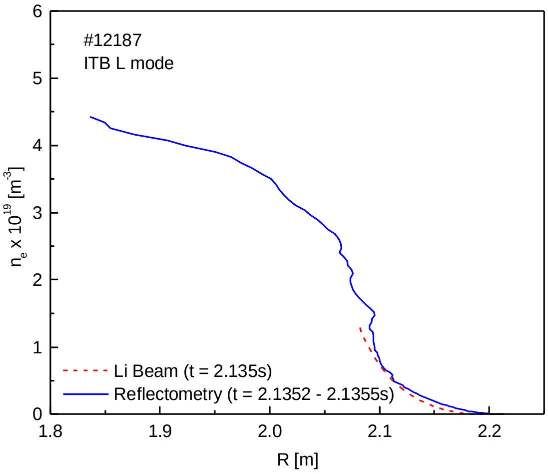


Fig. 6: *Density profiles from reflectometry and Li beam from a ITB L mode shot.*

the profiles were obtained at two different instants. Both profiles agree. Fig 7 represents another profile from an H mode shot with ITB in an instant acquired in the H phase of the plasma. For this case both profiles agree and it is possible to use Li beam data. There are other cases in H mode phase where the profiles present a different gradient at the edge.

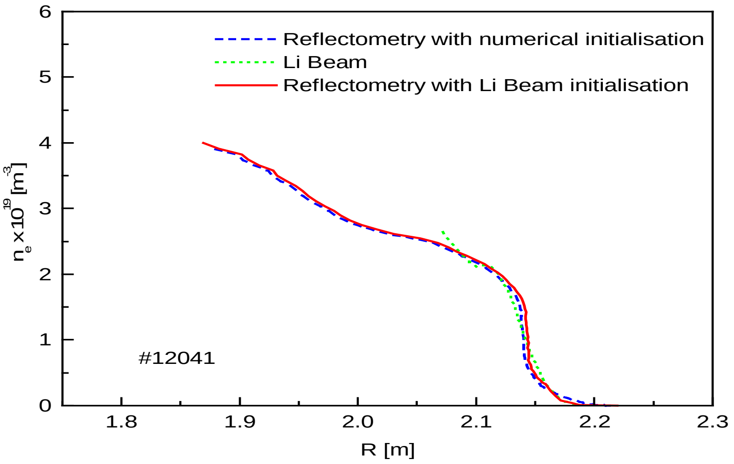


Fig 7 Refelctometry profile initialisation with Li beam data

Conclusions

The Li beam diagnostic can support the reflectometry with data averaged over 5 ms. A combination of both diagnostics has the ability of measuring density profiles from the very edge to regions far inside the core plasma with a high temporal resolution, thus expanding the performance of both systems. In this study we utilised Li beam data from the low density edge plasma for the initialisation of reflectometry measurements in different types of discharges. We discovered that the agreement of profiles obtained in the overlapping radial region depends on the plasma scenario. Limitations of the combination seem to appear in discharges with rapid phenomena, when both diagnostics measure different density profiles possibly due to quite different temporal resolution.

References

[1] M. Manso et al., 25th EPS Conference, Prague (1998)
[2] J. Schweinzer et al., Plasma Phys.Control.Fusion (1992) **34** 1173
[3] R. Brandenburg et al., Plasma Phys.Control.Fusion (1999) **41** 471
[4] R. Brandenburg et al., 24th EPS Conf., Europhys.Conf.Abstr. **21A** Part I (1997) 477