Model of electron velocity distribution function at JET divertor targets

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Motivation

Problem

Divertor LPs at TCV seem to overestimate the electron temperature by a factor of $\sim$5.
[J. Horáček et al., Journal of nuclear materials 313-316 (2003) 931-935]

This indicates that electron velocity distribution functions (EVDF) at divertor targets deviate significantly from maxwellian.

Solution

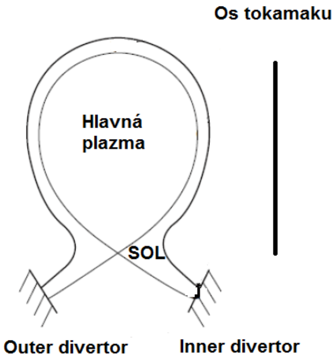
- Detailed, full, self-consistent PIC simulations [D. Tshkakaya et al., Journal of nuclear materials 415 (2011) S860-S864]
- **Simple model: Try to identify and describe the main mechanism responsible for T_e overestimation.**

In both cases the synthetic EVDF at the divertor target is constructed.

Geometry of the simple model

Divertor target and Scrape-off layer

- In tokamaks - field lines can be closed or open (due to solid surfaces). This defines the last closed flux surface.
- In a limiter configuration - limiters divertor configuration - divertor targets.
- The plasma confined outsied the LCFS is called the Scrape-off layer - SOL.
- Almost every charged particle entering the SOL terminates at the target.
- In this simple model, only 1-D movement of electrons along the field line will be considered (in a divertor configuration).

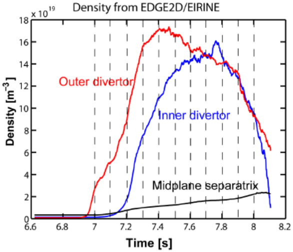


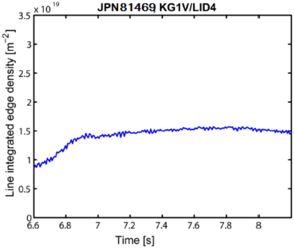
Simple model - description 1/4

Basic idea

- Large parallel gradients of T_e in SOL could lead to the enhancement of the tail of EVDF at the divertor targets.
- Langmuir probes evaluate T_e primarily from the tail of the EVDF which could explain the observed overestimation of T_e.

Input data: Parallel SOL T_e and n_e profiles computed by the EDGE2D/EIRENE fluid/Monte Carlo code.
JPN 81469, density ramp discharge until density limit.





Simple model - Description 2/4

Computation of the target EVDF:

1. An electron with velocity v_0 at the target is launched upstream by step $\mathrm{d}x$ and the probability of **collision** during this step is calculated (using the electron energy exchange mean free path λ): $\mathrm{d}p = \mathrm{d}x/\lambda(x)$
2. More steps are taken and the probability accumulates:

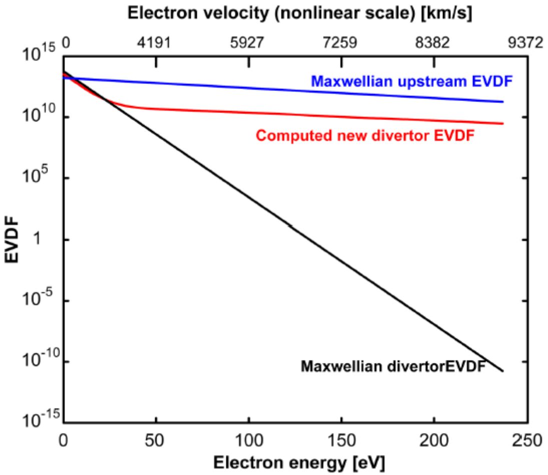
$$p(x, v_0) = \int_0^x \mathrm{d}p(x') = \int_0^x \frac{\mathrm{d}x'}{\lambda(v_0, T_e(x'), n_e(x'))}. \qquad (1)$$

3. until a location x^* where $p(x^*, v_0) = 1$ is reached.
4. The value of the target EVDF for velocity v_0 is calculated as a weighted average of Maxwellian distributions on $[0, x^*]$

$$f(v_0) = \frac{1}{x^*} \int_0^{x^*} S(x') f^{\mathrm{Max}}(T_e(x'), n_e(x'), v_0) \mathrm{d}x'. \qquad (2)$$

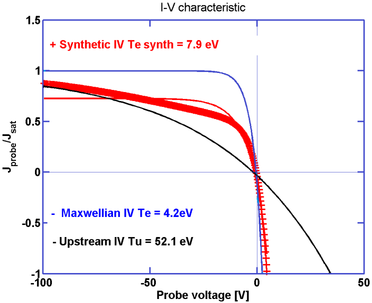
5. This is repeated $\forall v_0$ until the whole EVDF is computed.

Example of a perturbed EVDF



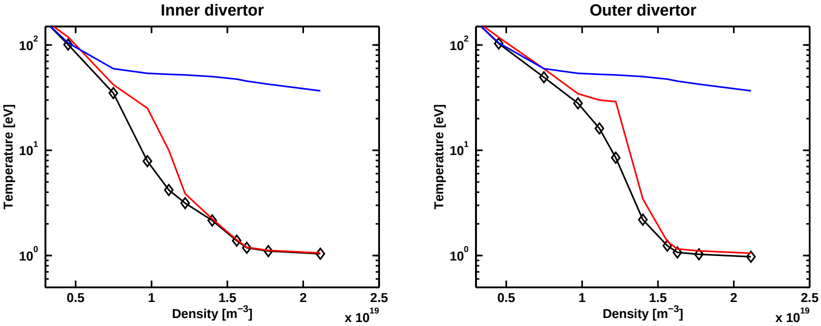
Computation of divertor probe IV characteristics:

1. From the synthetic EVDF, j_i, j_e at a given potential V_{prb} can be calculated.
2. IV characteristic: $j(V_{\mathrm{prb}}) = j_i - j_e$
3. Synthetic IV characteristic is fitted by $j_{prb} = en_{se}c_s\left(1 - \exp\left(\frac{e(V_{\mathrm{prb}} - V_{fl})}{kT}\right)\right)$, to get target synthetic T_{esynth} .



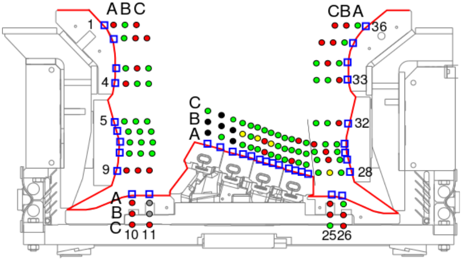
Results

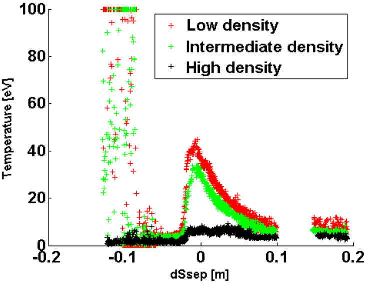
- Simulations suggest that probes should measure correctly for the low and high density cases.
- For intermediate densities, probes should overestimate the temperature by factor ~ 3.
- The expression used for the mean free path is a key player here.



Comparison with experimental data

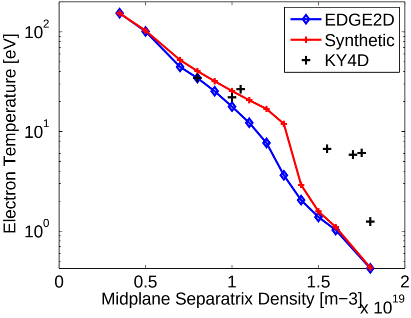
- Validated divertor LP radial profiles from JET have been obtained corresponding to density ramp up discharge 81469.
- Profiles obtained by sweeping the separatrix.

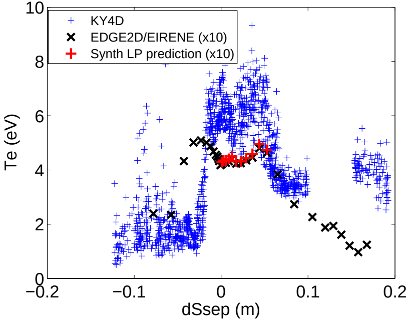




Comparison of experimental data with model prediction

- Left figure: Density scan, 5 mm from separatrix.
- Simulations show good agreement in the low and medium density area.
- For the more interesting high densities (high recycling, detached regimes) simulations do not predict overestimation, while probes seem to overestimate.
- Right figure: Looking at different radial positions does not bring any surprises (high density case).





Conclusion Future plans

Hypothesis:

- It appears that the model in its present status can not explain overestimation observed by diveror LPs, i.e. that fast electrons from hot upstream locations are not the dominant effect for the high density case.
- This conclusion was tentatively suggested in paper [J. Horáček et al., Journal of nuclear materials 313-316 (2003) 931-935] for TCV using a very similar analysis.
- Final goal is to present at the 2014 PSI conference in Japan.

Future plans:

- Try to benchmark our EVDF with the output from full kinetic codes (BIT1 - D. Tskhakaya, QPIC - V. Fuchs, J. Gunn).
- Use full kinetic codes to evaluate the LP IV characteristic at the divertor..