2D reconstruction of neutral density in the divertor region of ASDEX-U

Agostini Matteo

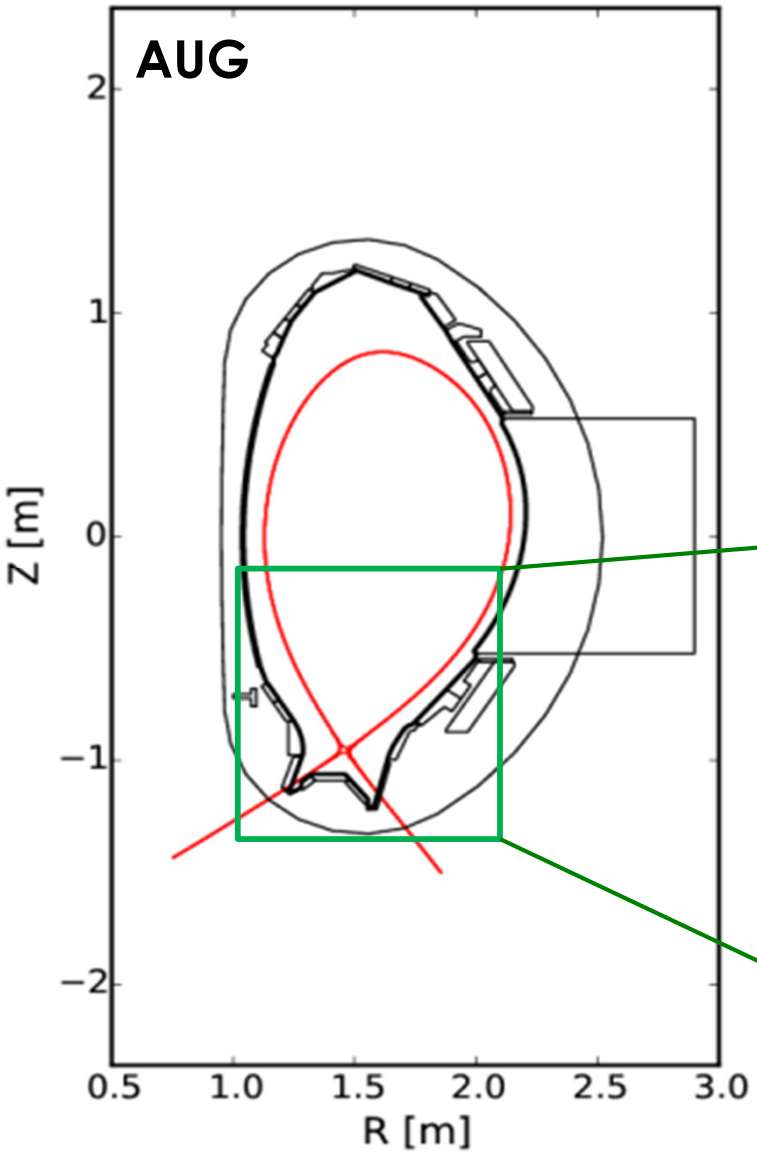
CONSORZIO RFX
Ricerca Formazione Innovazione

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

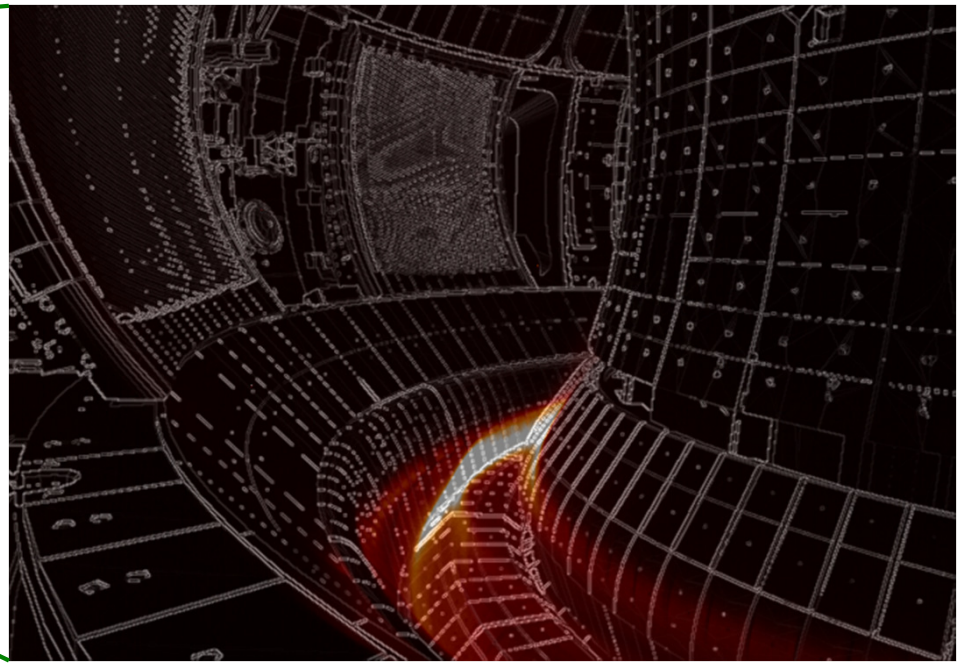
Introduction

- **Main objective:** estimate neutral profile in the divertor region
- Tomographic reconstruction of the 2D neutral emission profile (D_α / D_γ)
- Measure n_e with another diagnostic
- Obtain T_e and n_0

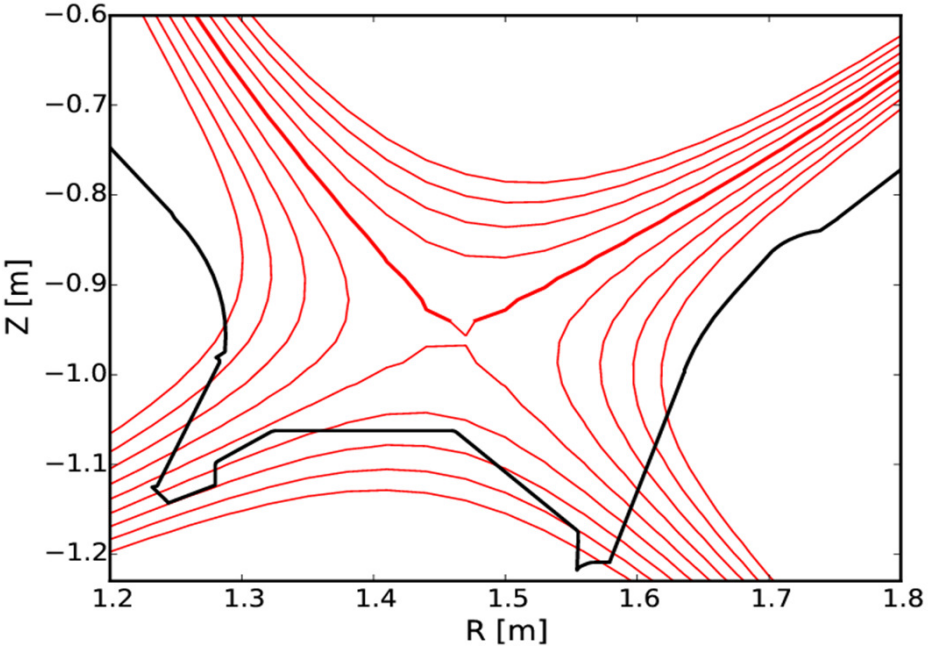
Diagnostic



- ✓ 2 CCD cameras :
  - D_α (656 nm) and D_γ (434 nm)
  - Absolute calibrated
  - Look at the same region



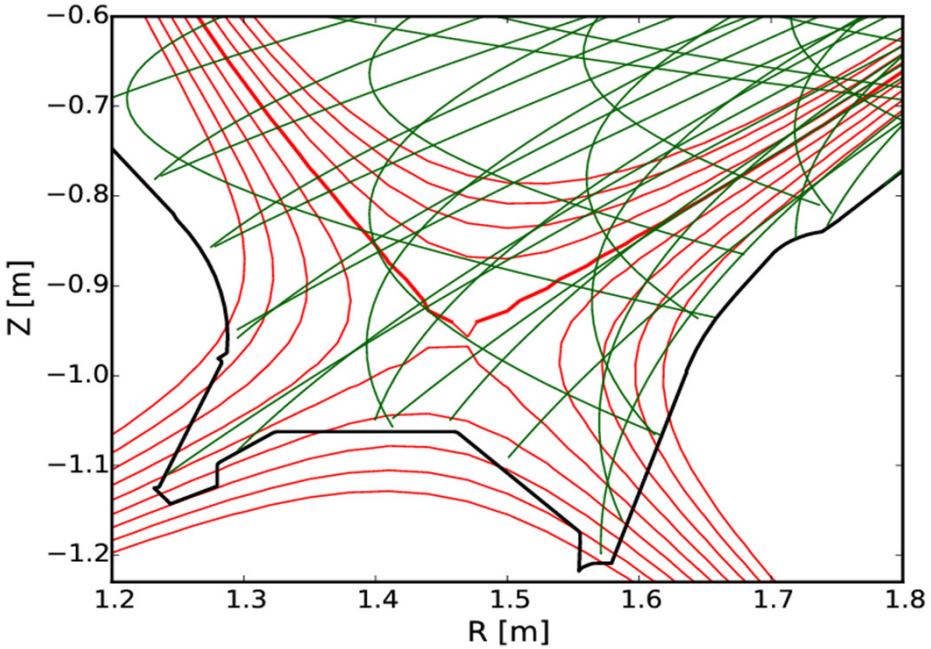
Divertor tomography



First step: obtain 2D emission ε from line integrated signals

Assuming no dependence on toroidal angle: ε = ε(R,Z)

Divertor tomography



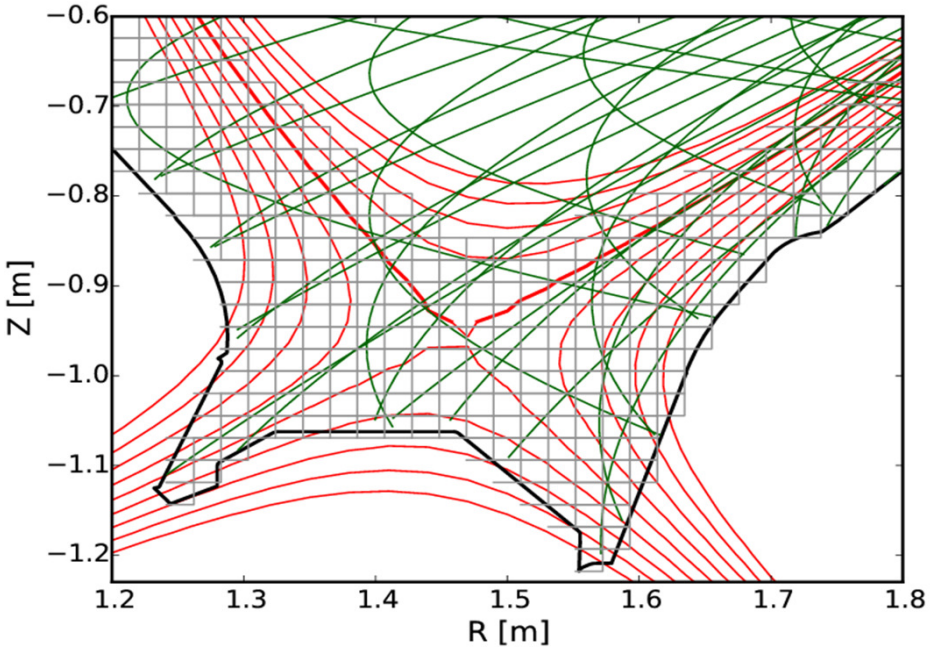
First step: obtain 2D emission ε from line integrated signals

Assuming no dependence on toroidal angle: ε = ε(R,Z)

In this plane the lines of sights intersect each other

Tomographic inversion is possible

Tomographic technique



First step: obtain 2D emission ε from line integrated signals

Assuming no dependence on toroidal angle: ε = ε(R,Z)

In this plane the lines of sights intersect each other

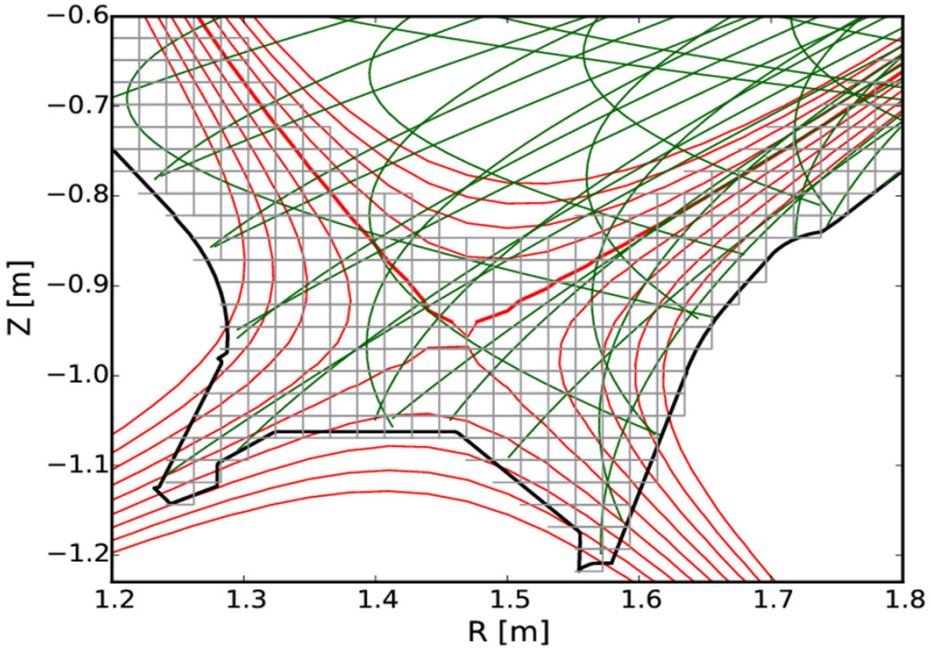
Tomographic inversion is possible

Pixels technique in order to avoid too many a priori constraints on the emission shape

Pixels with constant emission $\mathbf{I} = \mathbf{A}\,\varepsilon$

Emission only outside the separatrix

Reflection problem



AUG has full tungsten first wall
Problem: light reflection

Reflection impact minimized looking only at the divertor

No reflection in this presentation

AUG tomography and reflections:
*J. Harhausen et al., Plasma Physics Controlled Fusion , **53** (2011) 025002*

Tiles reflection (Mo and C) and effect on the measurements:
*E. M. Hollmann et al., Rev.Sci.Instrum. **74** (2003) 3984*
*E. M. Hollmann and A. Yu. Pigarov, Contrib. Plasma Phys. **44** (2004) 301*

Big problem for ITER:
*S.Kajita et al., Plasma Physics Controlled Fusion , **55** (2013) 085020*
*S.Kajita et al., Nuclear Fusion, **57** (2017) 116061*

Inversion technique

~ 40000 LoSs looking at the divertor region

~ 400 pixels

Simultaneous **A**lgebraic **R**econstruction **T**echnique (SART) for the inversion

$$\varepsilon_i^{k+1} = \varepsilon_i^k + \frac{\sum_{j=1}^{\text{nlos}} \left(a_{i,j} \cdot \frac{I_j - \sum_{i=1}^{\text{npix}} \varepsilon_i^k \cdot a_{i,j}}{\sum_{i=1}^{npix} a_{i,j}} \right)}{\sum_{j=1}^{\text{nlos}} a_{i,j}}$$

Positive emission constrain: at each step k $\varepsilon_i^k=0$ if negative

No input from equilibrium

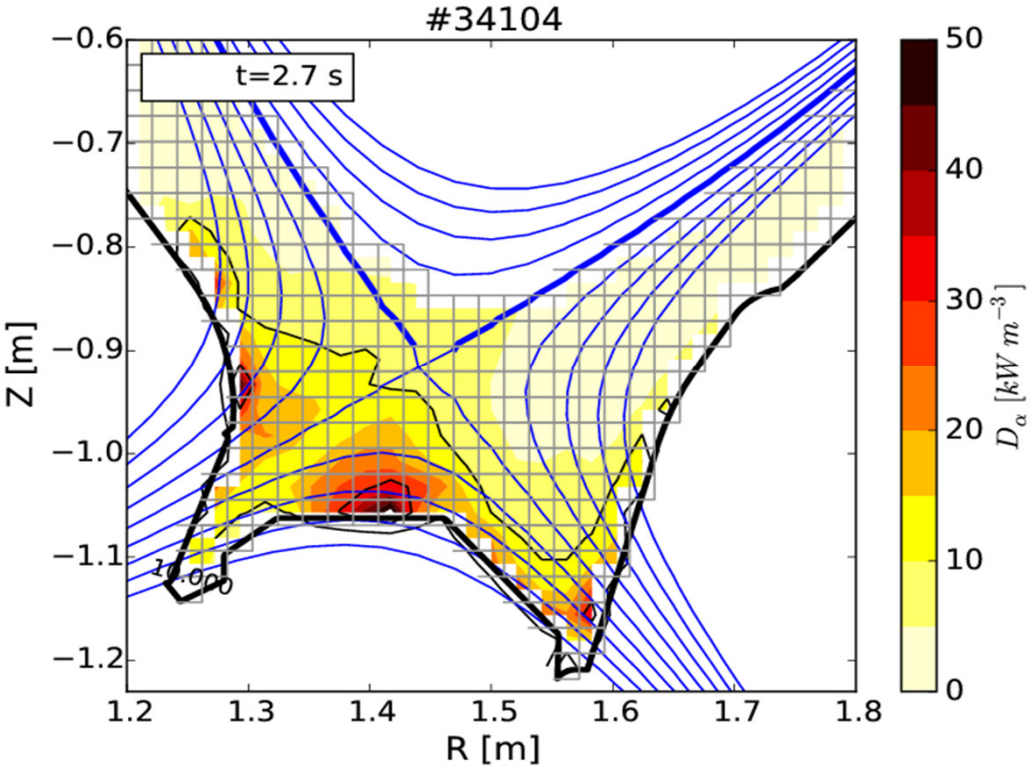
No regularization

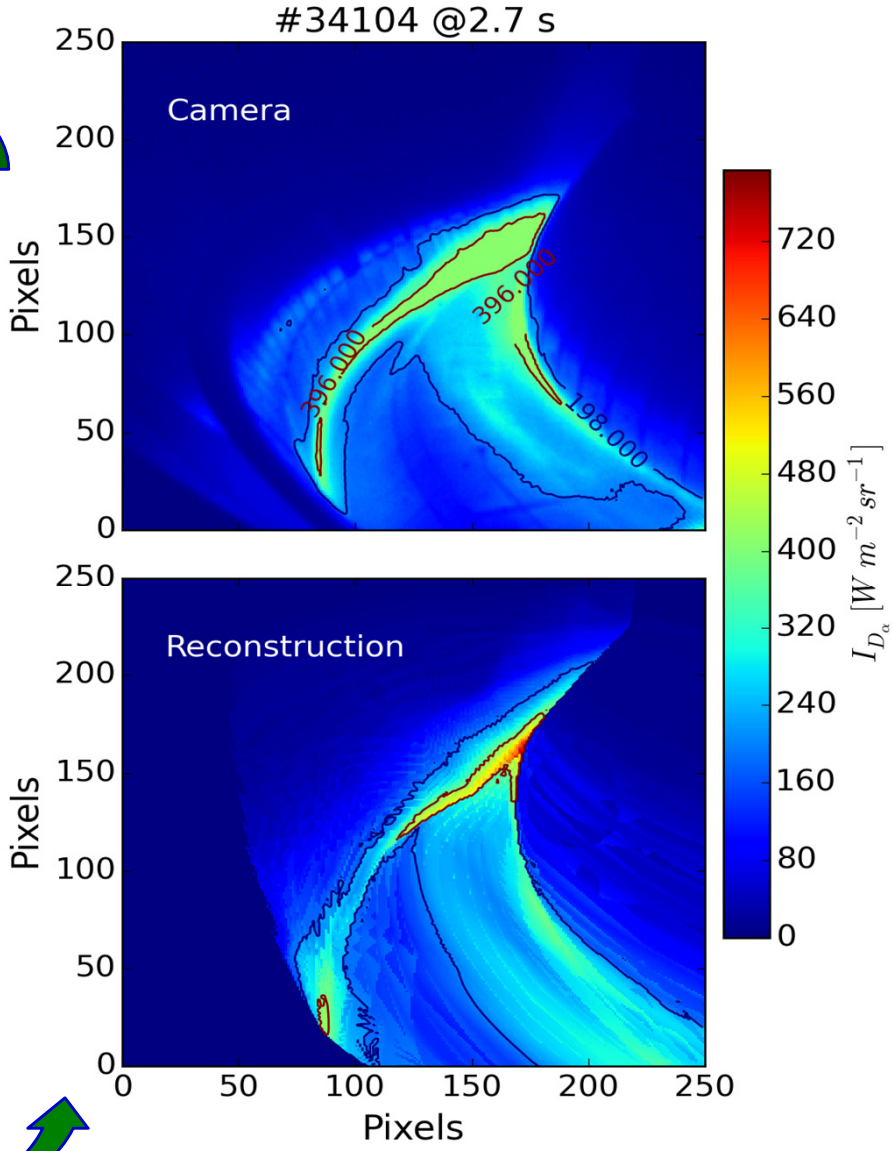
*A. H. Andersen and A. C. Kak, Ultrasonic Imaging , **6** (1984) 81*
*M.Agostini et al, Phys. Rev. ST Accel. Beams **14**, (2011) 102801*

Example of reconstruction: D_α

From integrals to 2D emission

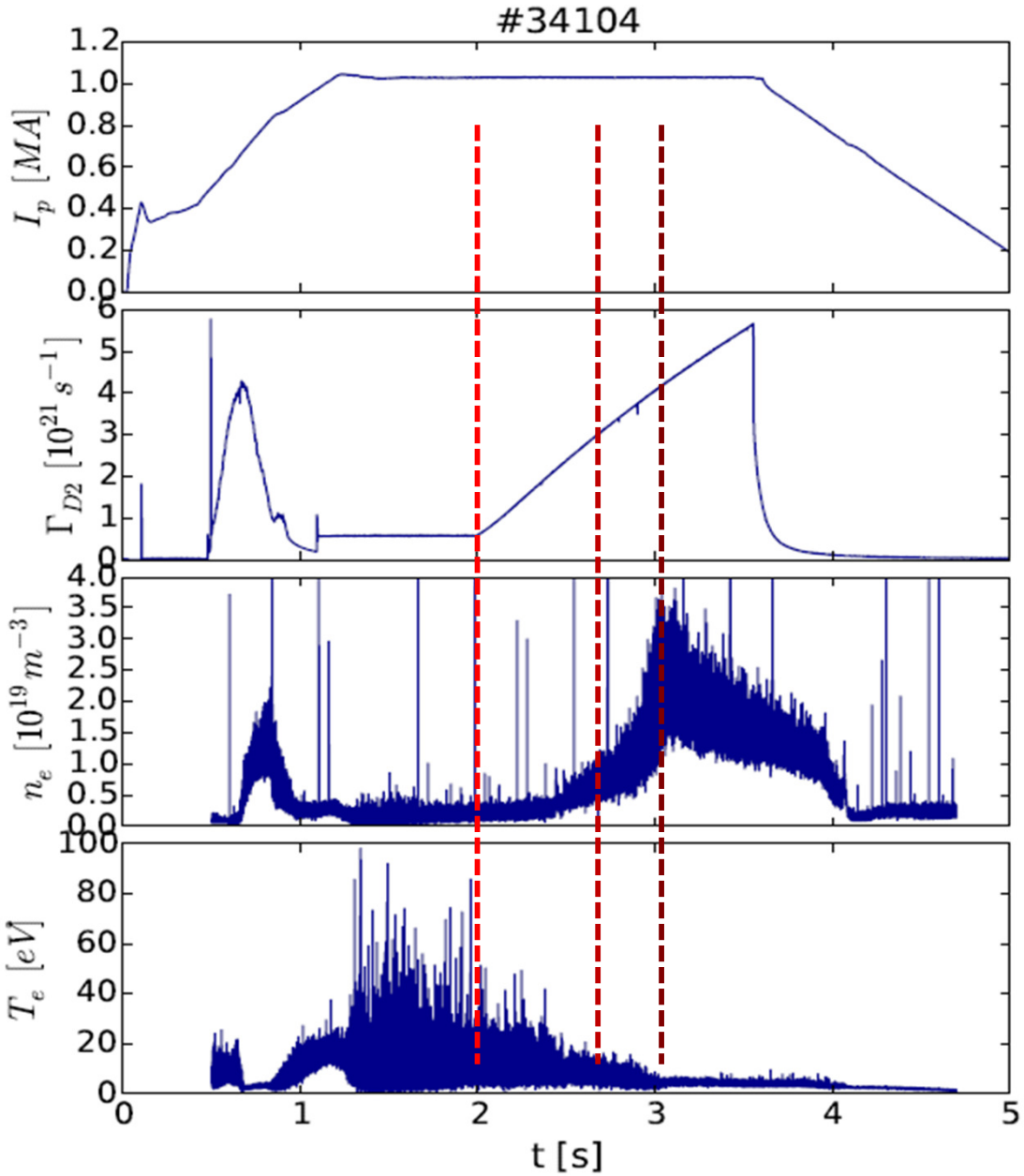
D_α





From emission to integrals

#34104

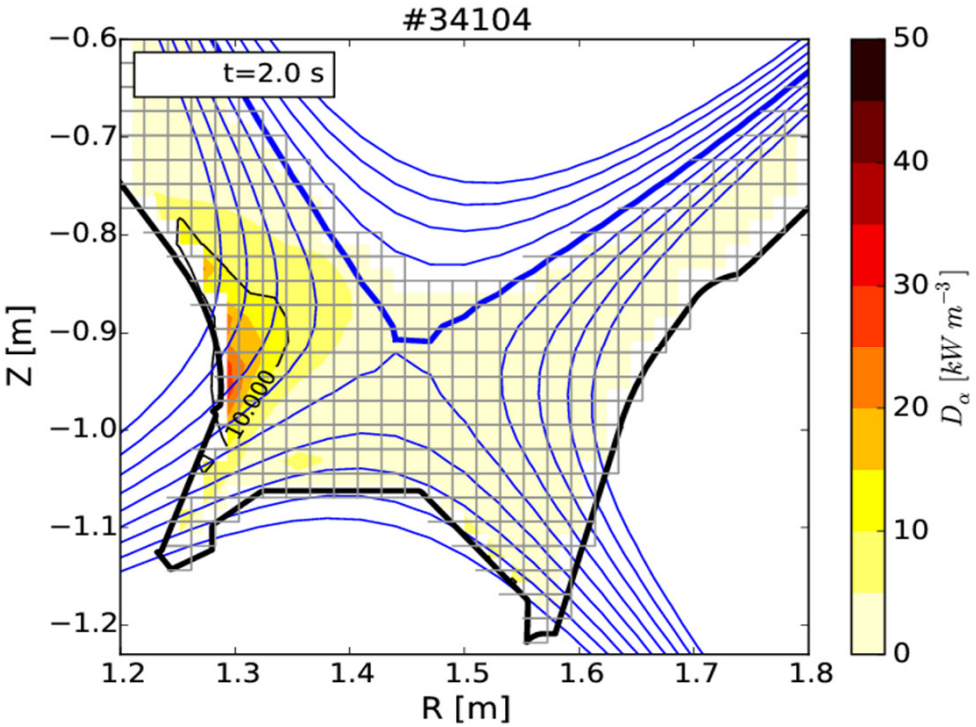


L-mode discharge with D_2 puffing

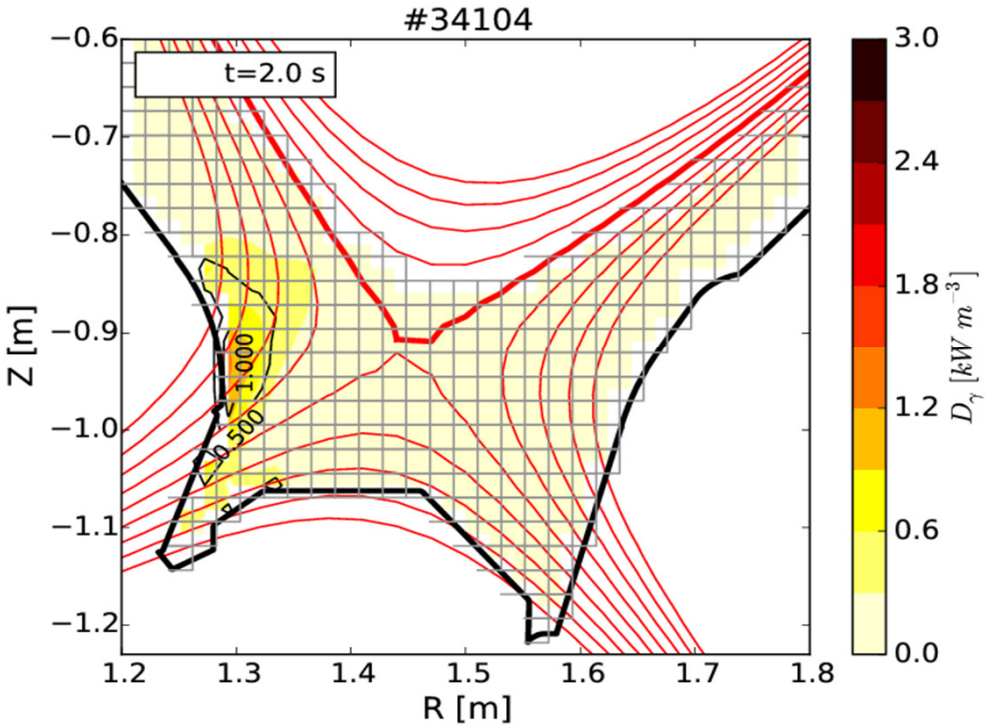
Electron density and temperature measured by Langmuir probe in the outer divertor target

Neutral emission 2s

D_α



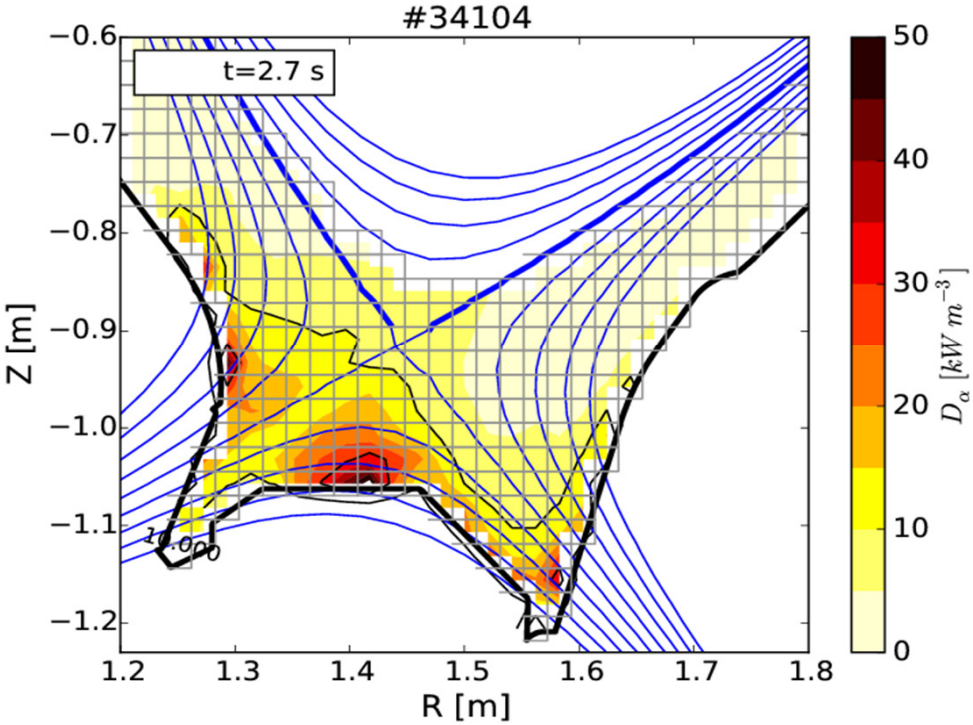
D_γ



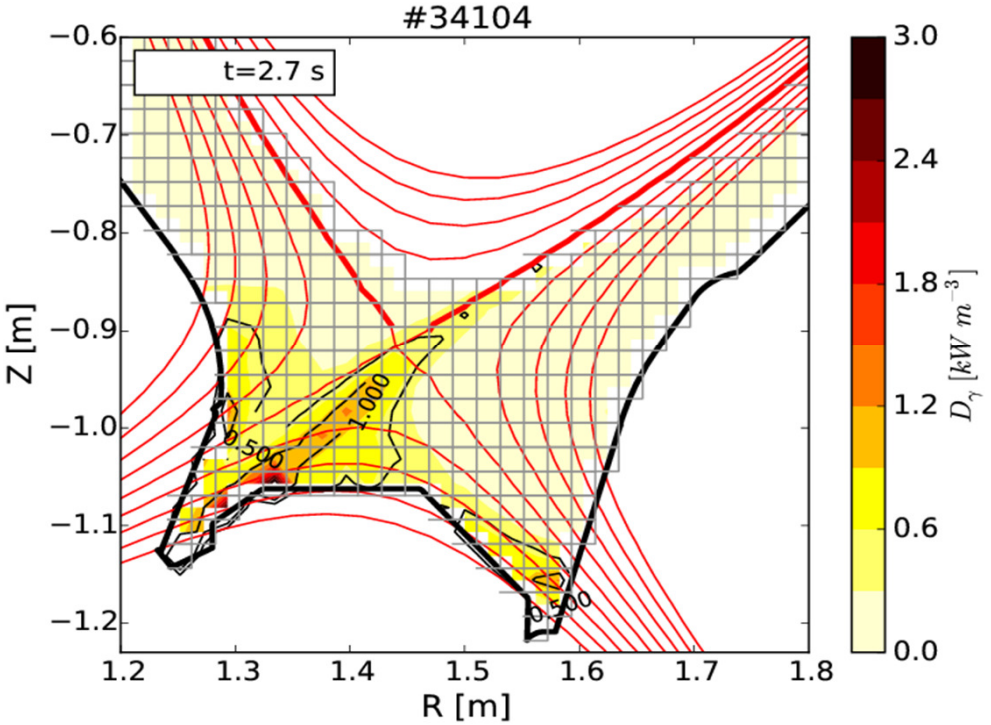
Emission localized in the inboard side of the divertor

Neutral emission 2.7s

D_α



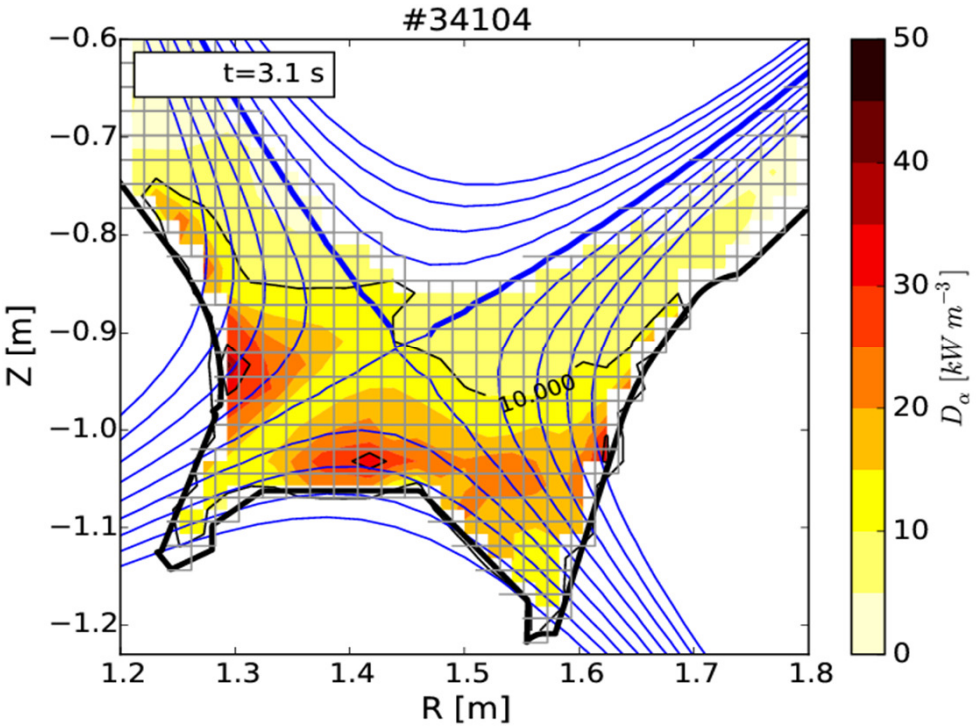
D_γ



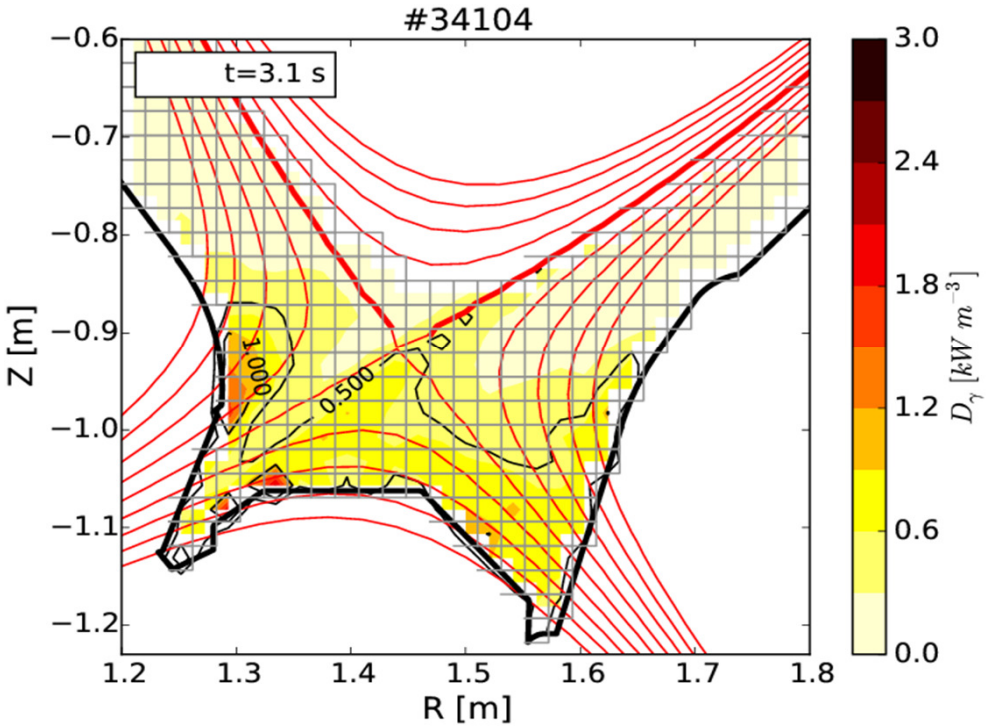
Emission moves toward the separatrix
Different patterns between D_α and D_γ

Neutral emission 3.1s

D_α



D_γ



Estimating neutral density

Work in progress…

Estimating neutral density

D_α and D_γ emissions depend on electron and neutral density (n_i=n_e)

$$\epsilon = PEC^{ex}\, n_e\, n_0 + PEC^{rec}\, n_e\, n_i$$

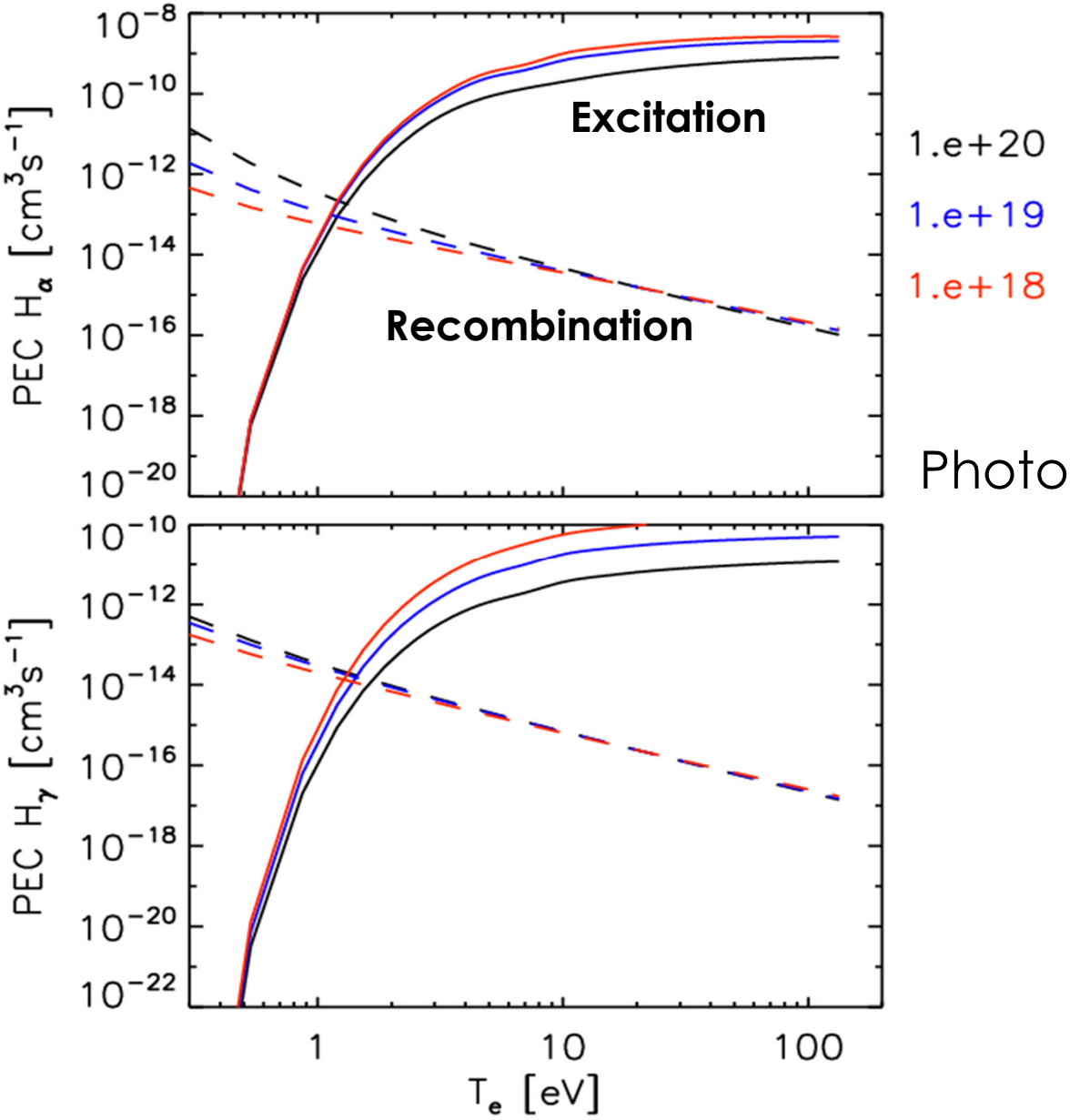
Coefficients PEC = PEC(n_e,T_e)

PEC^{rec} is comparable to PEC^{ex} for D_γ at low Te: Te ≤ 2 eV

Two experimental estimates (emissions) and three unknown n_e,n_0, T_e

Measuring n_e at the divertor it possible to obtain n_0, T_e

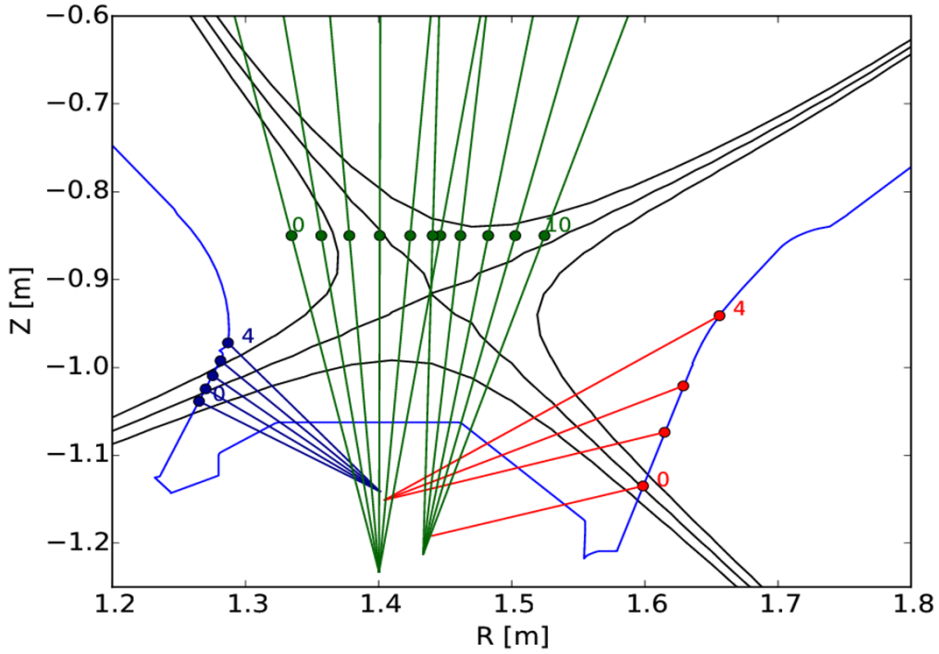
PECs

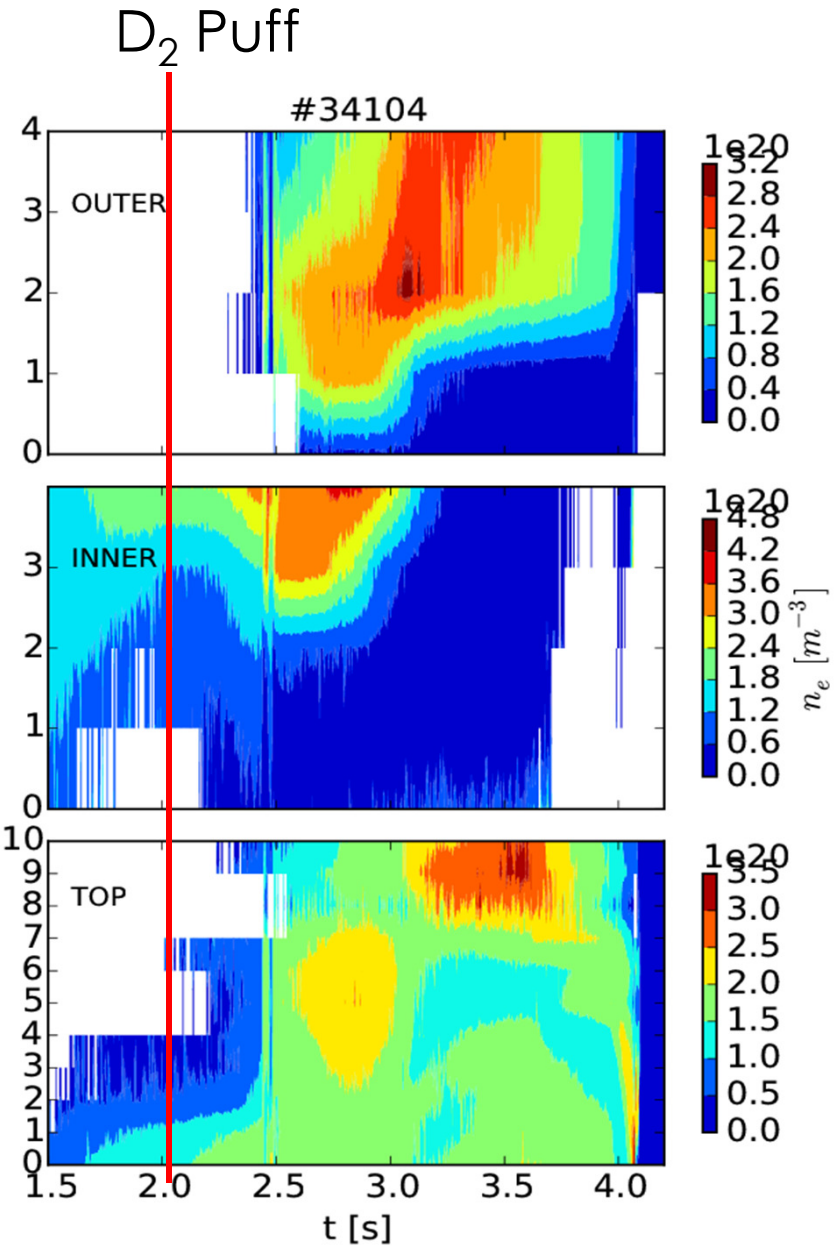


Photon emission coefficients from ADAS

http://open.adas.ac.uk/

n_e from Stark broadening



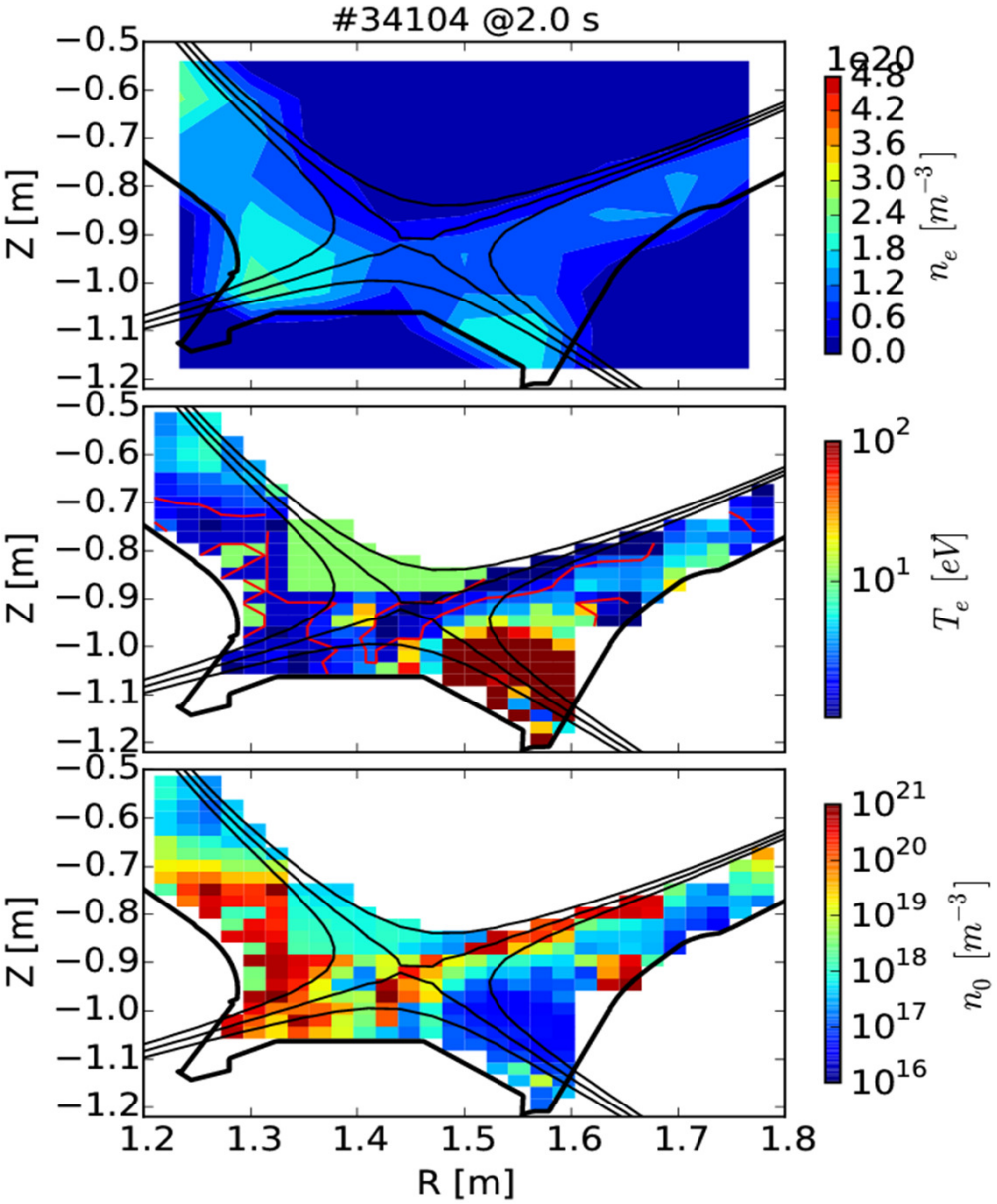


Stark broadening diagnostic gives line averaged n_e in the divertor region

With a tomographic inversion low resolution n_e in 2D is obtained

S.Potzel et al., Plasma Phys. Control. Fusion, ***58****, (2014) 025010*

Divertor Evolution

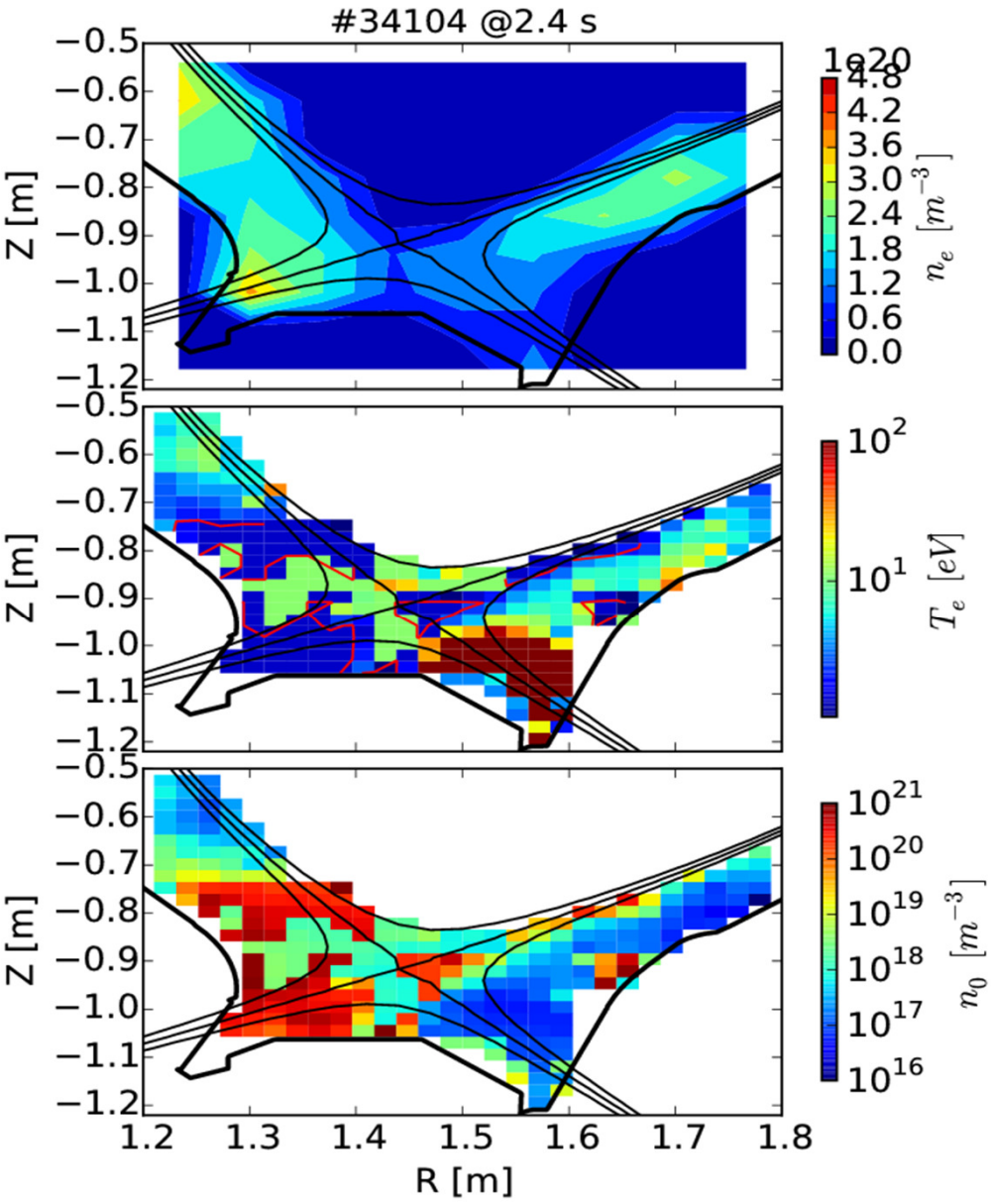


Electron density from inversion of Stark broadening diagnostic

Electron temperature

Neutral density

Divertor Evolution

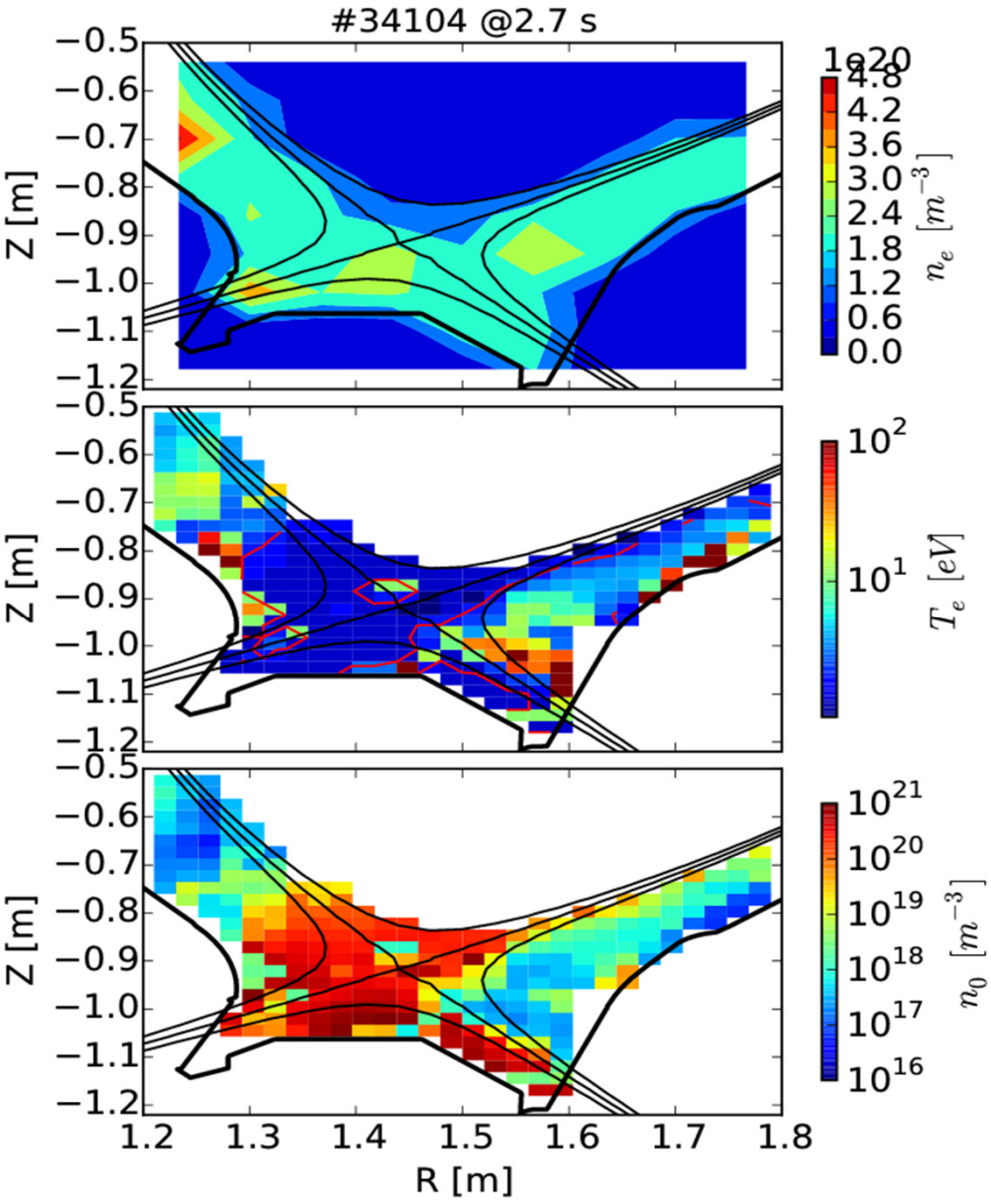


Electron density from inversion of Stark broadening diagnostic

Electron temperature

Neutral density

Divertor Evolution

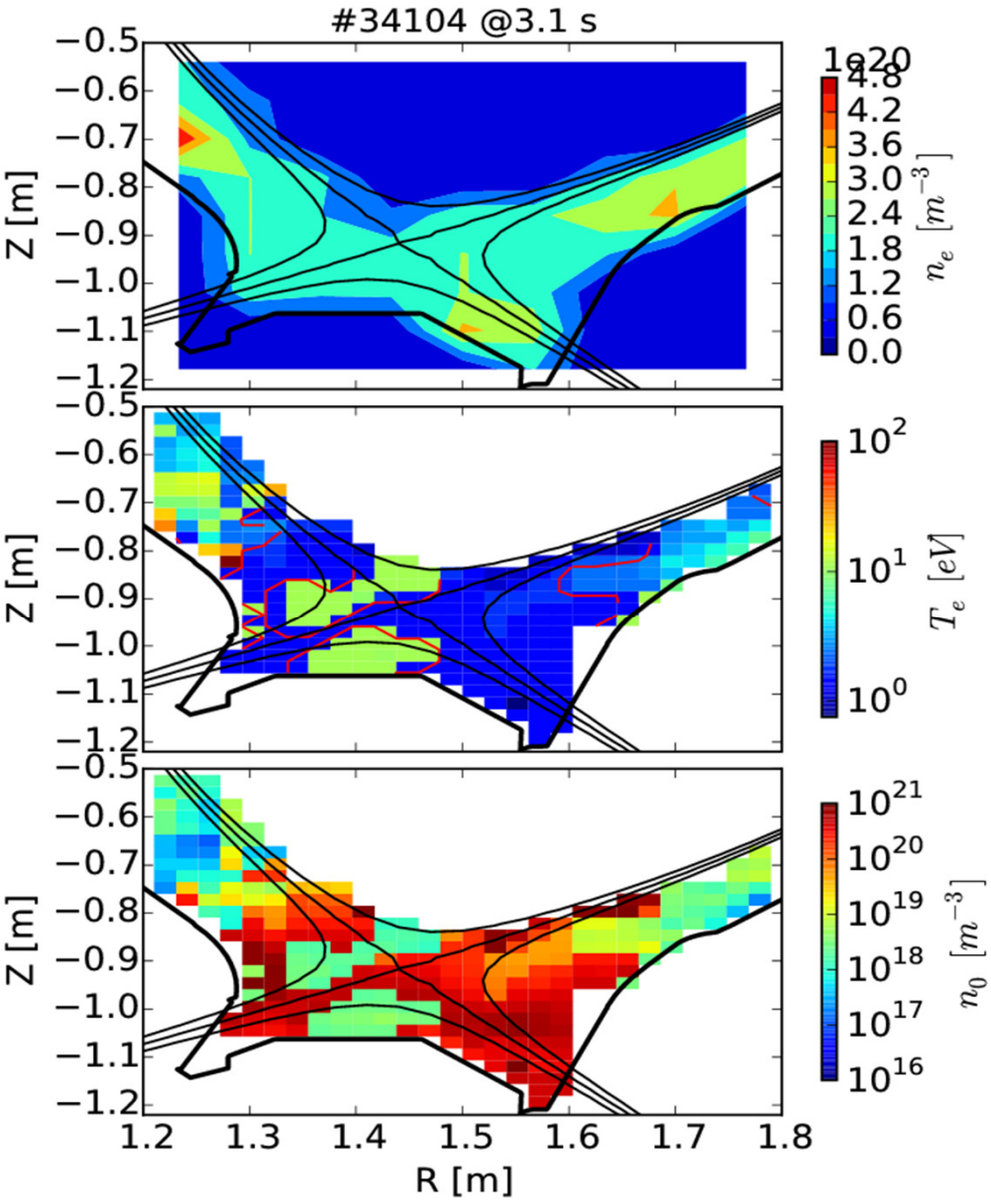


Electron density from inversion of Stark broadening diagnostic

Electron temperature

Neutral density

Divertor Evolution

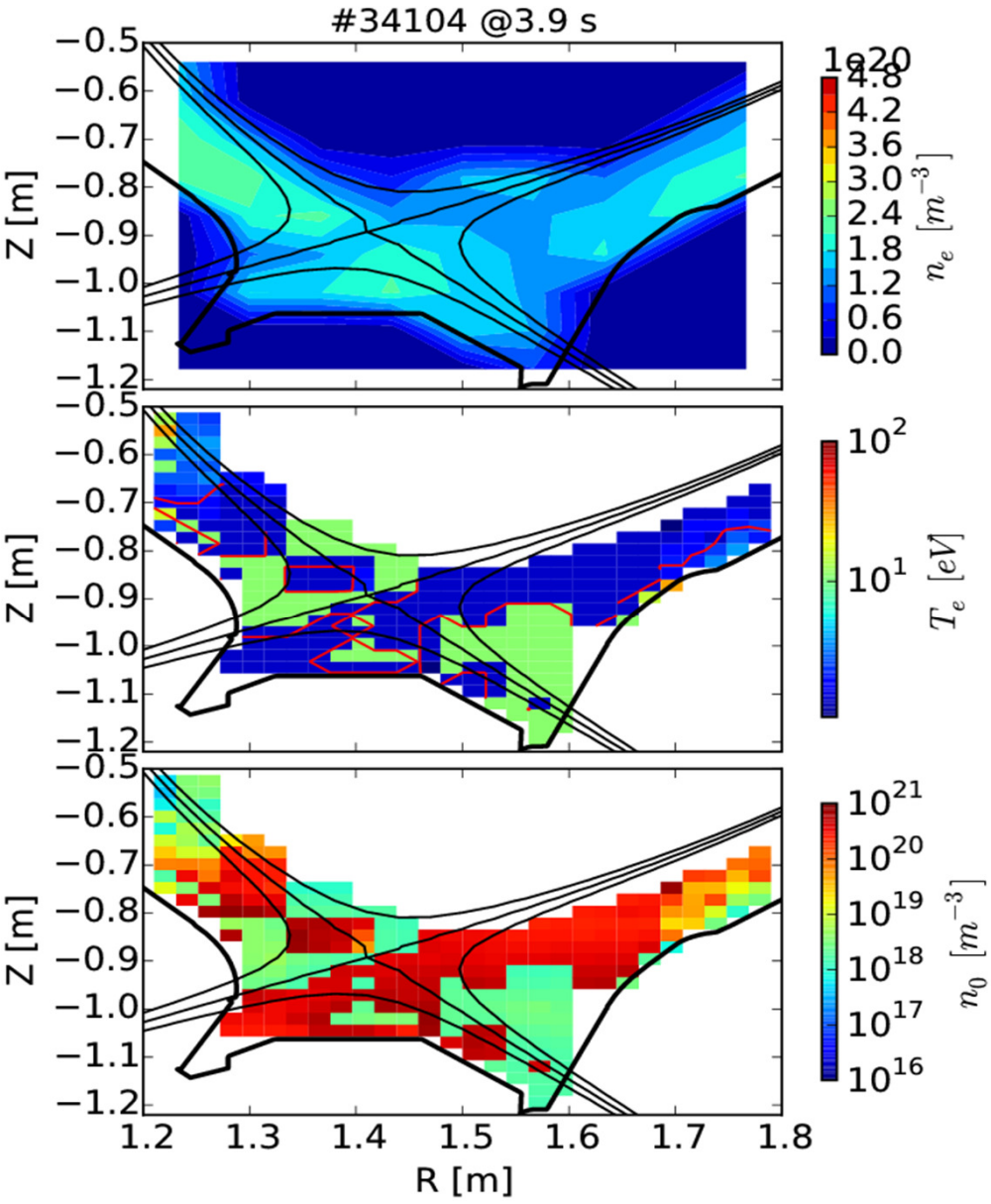


Electron density from inversion of Stark broadening diagnostic

Electron temperature

Neutral density

Divertor Evolution



Electron density from inversion of Stark broadening diagnostic

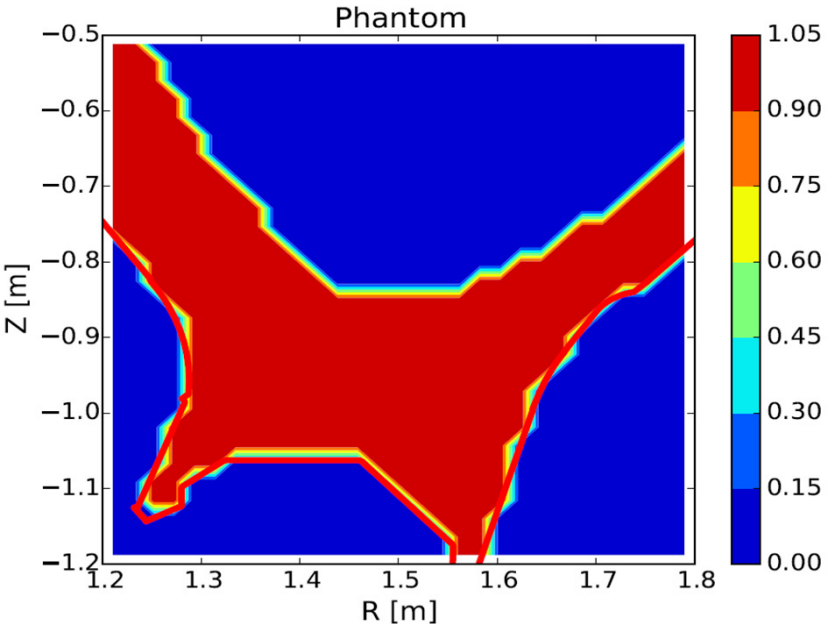
Electron temperature

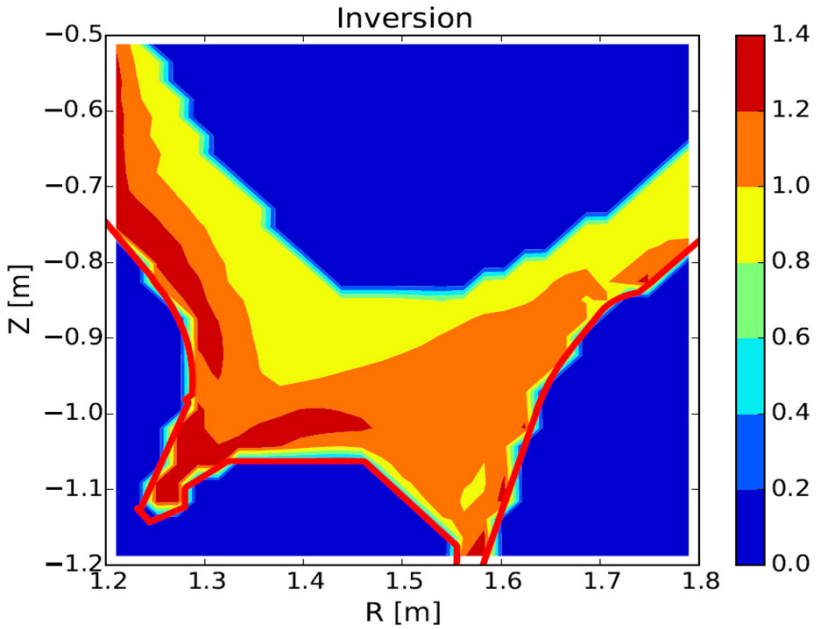
Neutral density

Conclusions

- Tomographic algorithm for D_α and D_γ emission in the divertor region developed
- Estimate of neutral density can be obtained
- Analysis of time evolution of neutral emission and neutral density to be done for clarifying their role in the electron profiles

Test



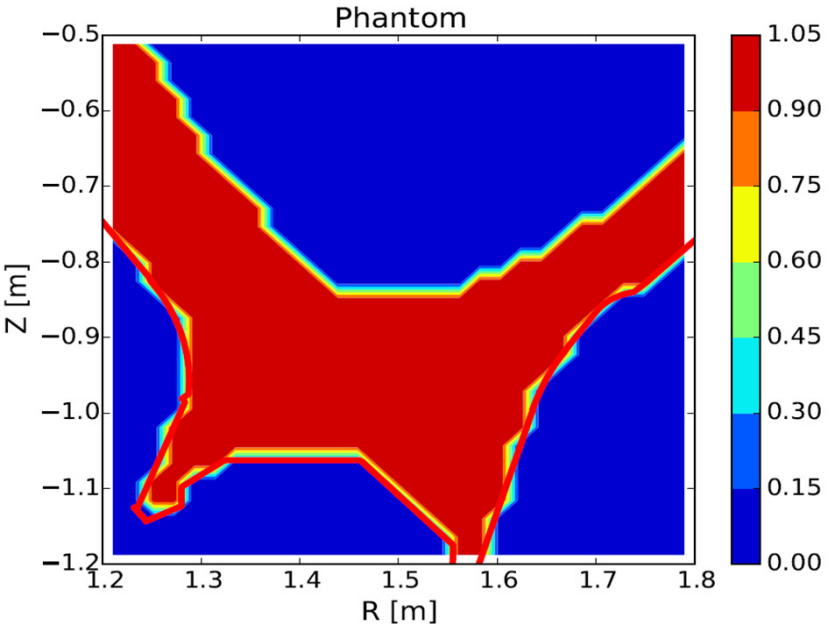


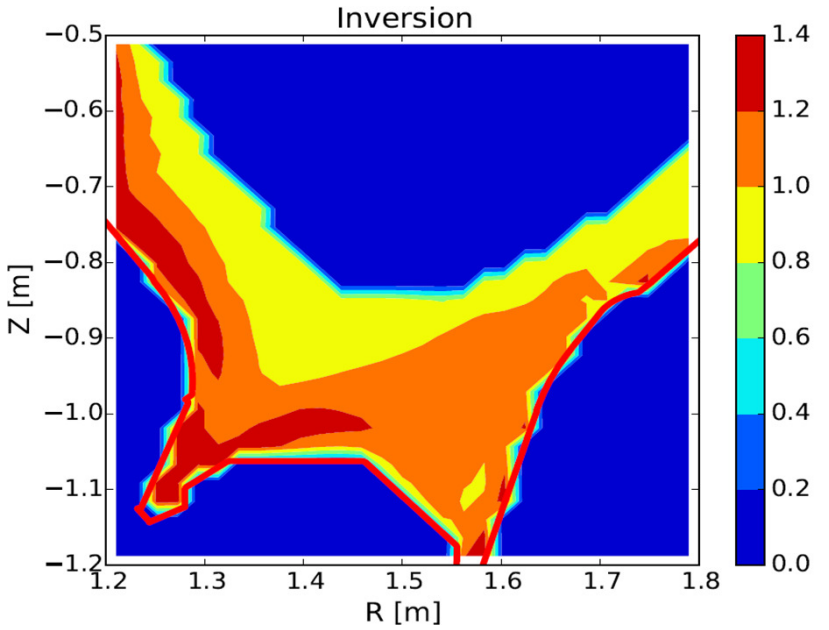
Uniform phantom simulated

The inversion is good

Some limitations near the separatrix where there are few LoSs intersections

Test



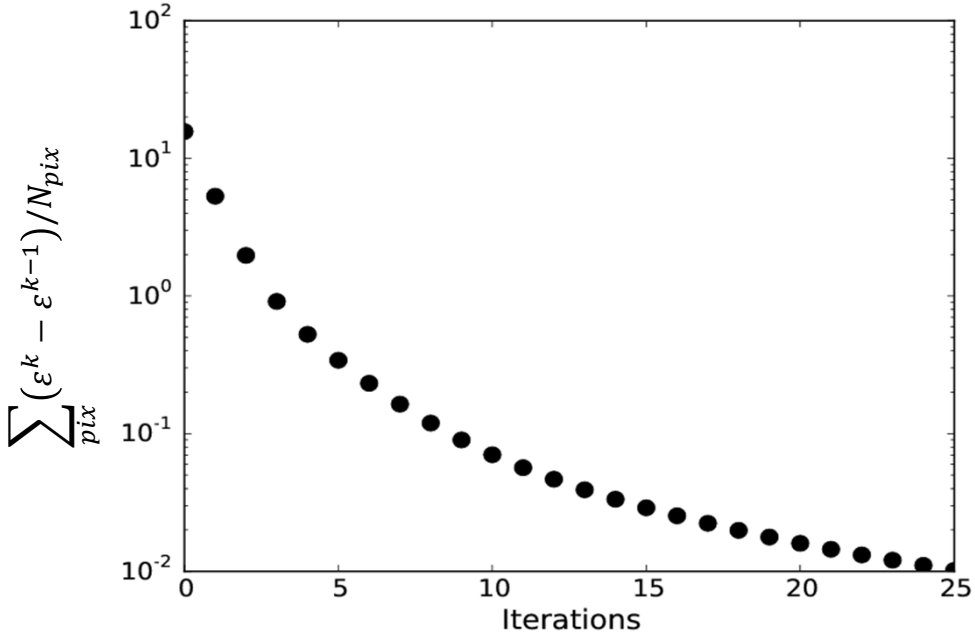


Uniform phantom simulated

The inversion is good

Some limitations near the separatrix where there are few LoSs intersections

Convergence is quite rapid

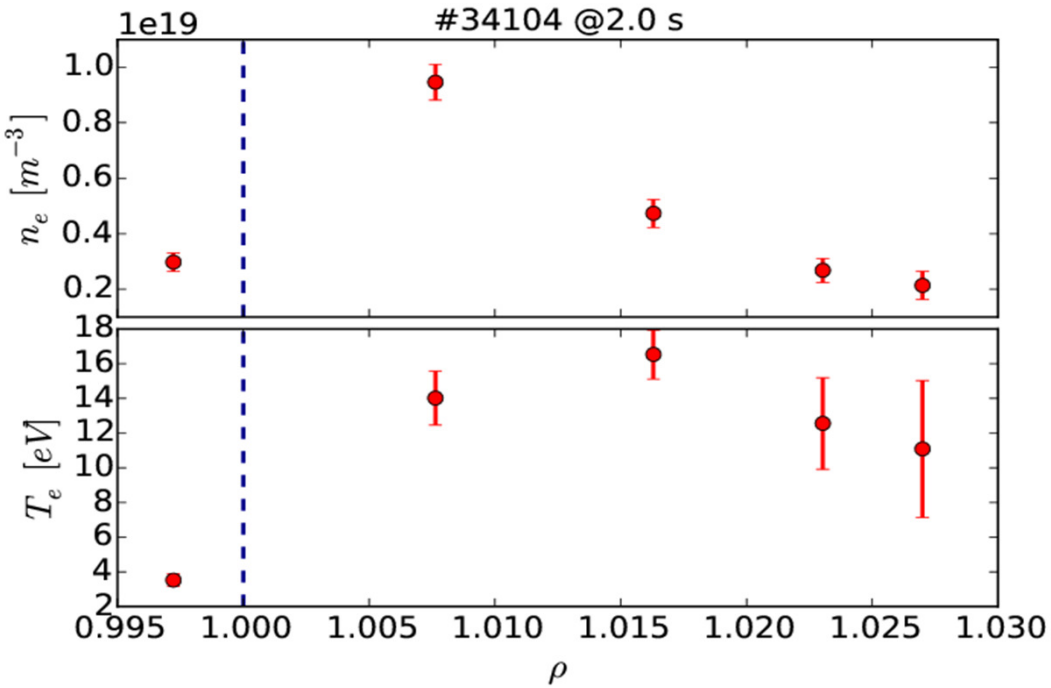


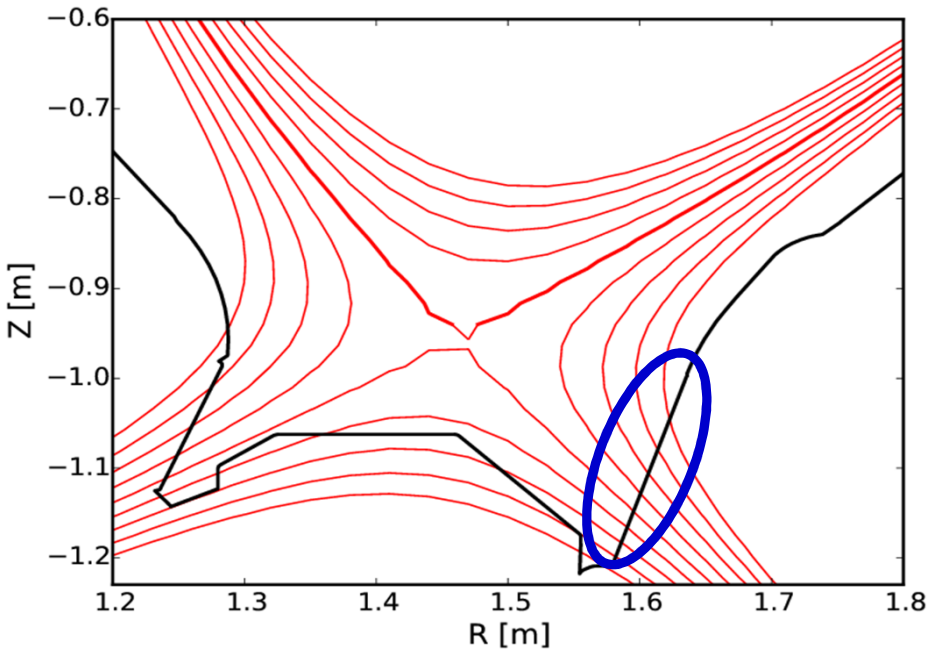
Langmuir probe profiles

n_e, T_e measured in the outer divertor target

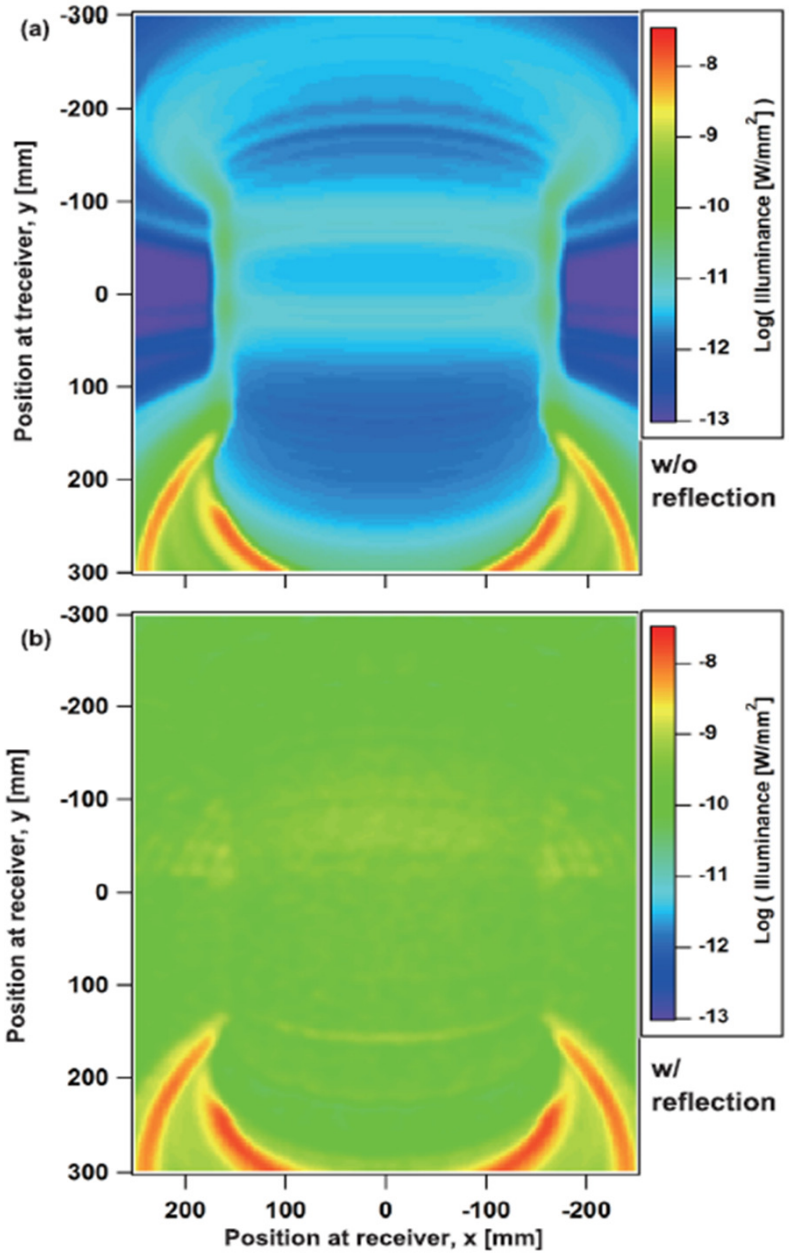
T_e is almost constant along ρ
Spectroscopic coefficients do not strongly depend on T_e

Assumption: all the pixels have $T_e = \langle T_e \rangle$
Two measurements and two unknowns





ITER simulations



No reflections

With reflections

S.Kajita et al., Nuclear Fusion, ***57*** *(2017) 116061*

W reflection (AUG)

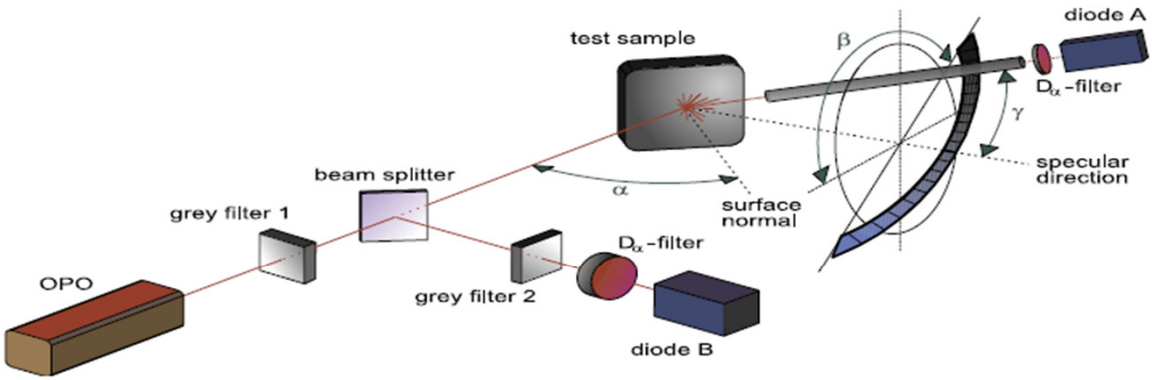


Figure A1. Scheme of the setup to measure diffuse reflectivity, solid angle resolved.

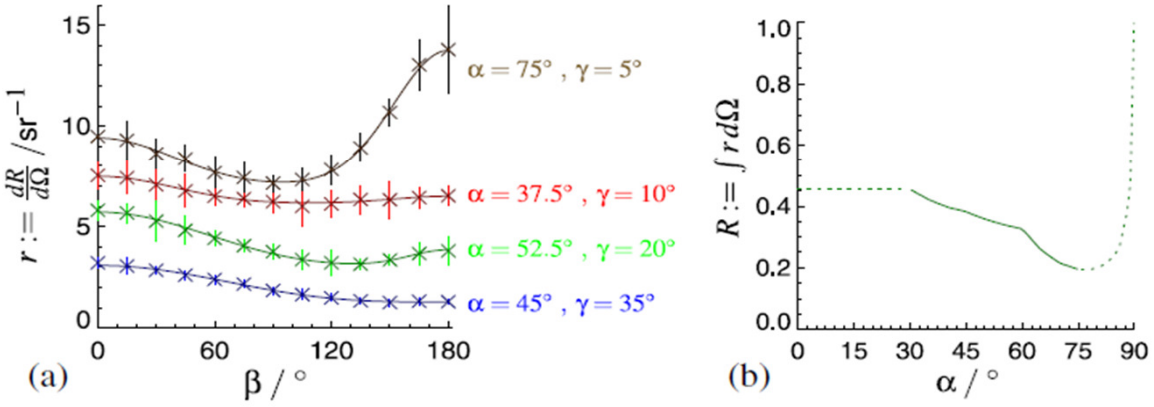


Figure A2. r-series on β for fixed α and γ (a) and total reflectivity R of the r-model (b) ($\gamma \leqslant 38\,^\circ$), measured (solid), extrapolated (dotted).

Plasma Phys. Control. Fusion **53** (2011) 025002 J Harhausen *et al*

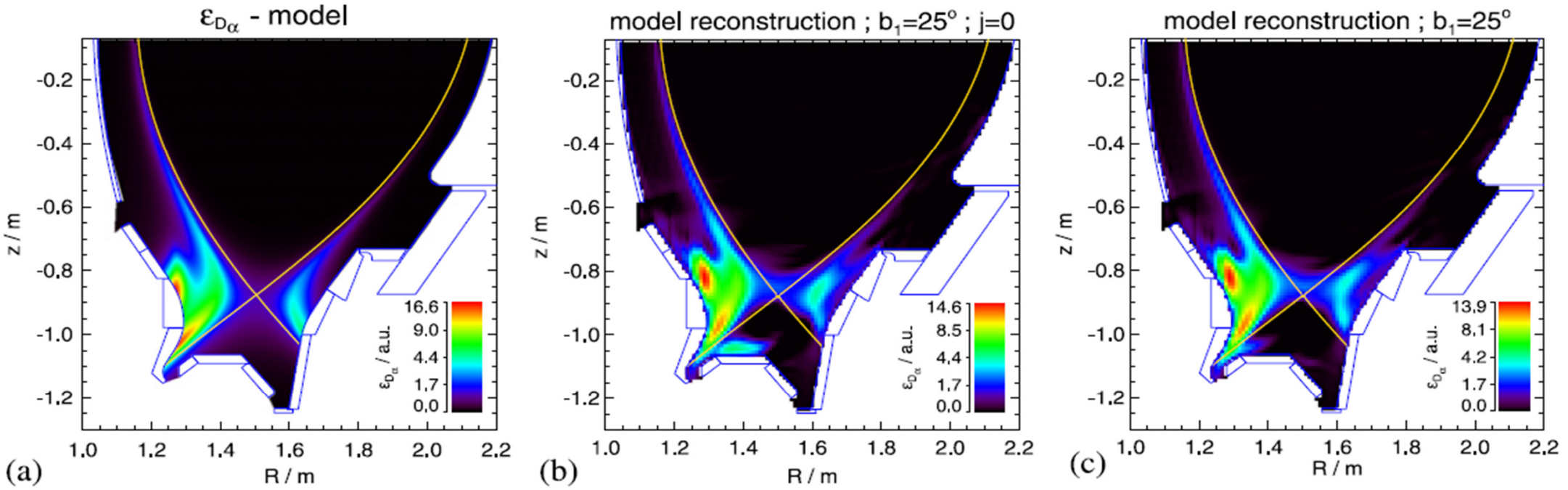


Figure 6. Profile model (*a*) to provide phantom data, profile reconstruction without (*b*) and with (*c*) the consideration of diffuse reflection.

C-MOD Mo

Rev. Sci. Instrum., Vol. 74, No. 9, September 2003

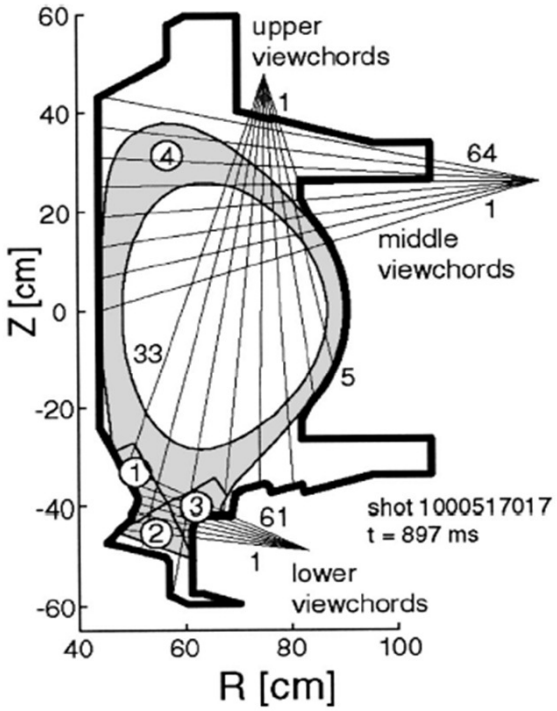


FIG. 8. C-Mod cross section showing the diode view chord geometry and the four regions used to approximate the spatial structure of the plasma D_α emission.

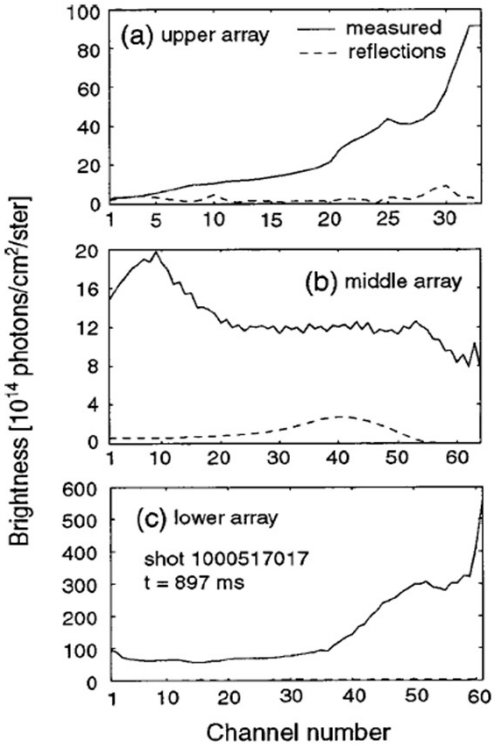


FIG. 9. C-Mod D_α filterscope data during L-mode discharge showing total measured signal and estimated contribution from reflections for (a) upper array, (b) middle array, and (c) lower array.

DIII-D C

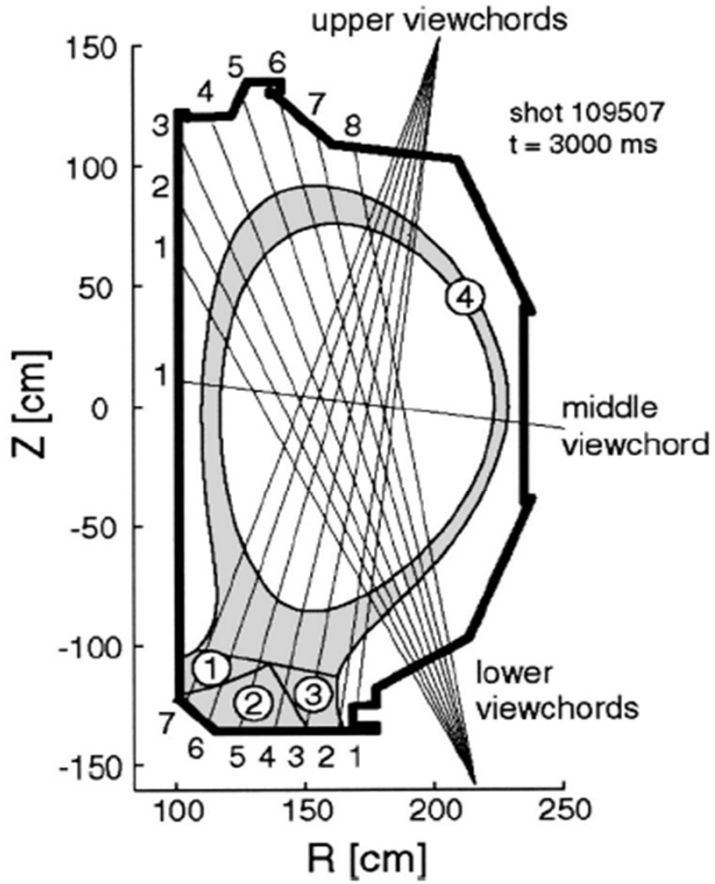


FIG. 5. DIII-D cross section showing the filterscope view chord geometry and the four regions used to approximate the spatial structure of the plasma D_α emission.

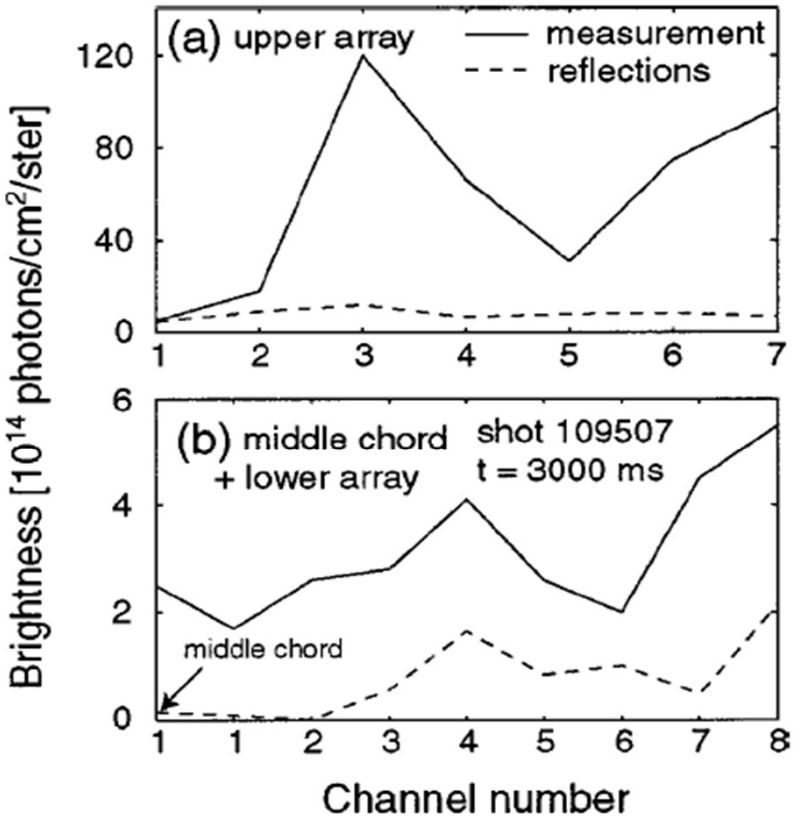


FIG. 6. DIII-D D_α filterscope data during L-mode discharge showing total measured signal and estimated contribution from reflections for (a) upper array and (b) lower array.