EUROPEAN FUSION DEVELOPMENT AGREEMENT

THE EFFECT OF THE ETB ON THE IMPURITY TRANSPORT

P Belo[1], C. Giroud[2] , V. Parail[2], G. Corrigan[2], J Hogan[3], D. Heading[2], J. Spence[2], W. Fundamenski[2], J. Strachan[4], M.G. O'Mullane[2] *and JET EFDA contributors* [b]

[1]*EURATOM/IST Fusion Association, Centro de Fusão Nuclear, Av. Rovisco Pais 1049-001 Lisboa Portugal*

[2]*EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon OX14 3DB, UK;*

[3]*Oak Ridge National Laboratory, Oak Ridge. TN, USA*

[4]*PPPL Princeton University, Princeton NJ, USA*

[b] appendix of J.Pamela, JET-EFDA Team in Fusion Energy 2004 (Proc. 20th Int. Conf., Vilamoura, 2004), IAEA Vienna 2004 CD-Rom file PD/1

INSTITUTO SUPERIOR TÉCNICO

Outline

- **Introduction**
- **What is observed in different machines in H mode plasmas**
  - Transport coefficients in ELM free periods
  - Transport coefficients during the ELM
- **Impurity quantity control inside the barrier (r/a<0.9)**
  - Outward convective velocity
  - Gas puff
- **Modelling the Effect of the ETB on the impurity transport using JETTO/SANCO and EDGE2D/NIMBUS**
  - Gas puff
  - ELMs
- **Conclusions**

Introduction

- **PLASMA CORE:**
  - The region is 0.9 > r/a ≥ 0;
  - Accumulation: impurity density profile evolves towards a stronger peaking than the main ion density profile.
  - The transport is mainly anomalous
- **ETB:**
  - The region is 0.9 ≥ r/a ≥ 1.0;
  - Controls the quantity of impurities in the plasma core and is mainly controlled by the neo-classical transport:

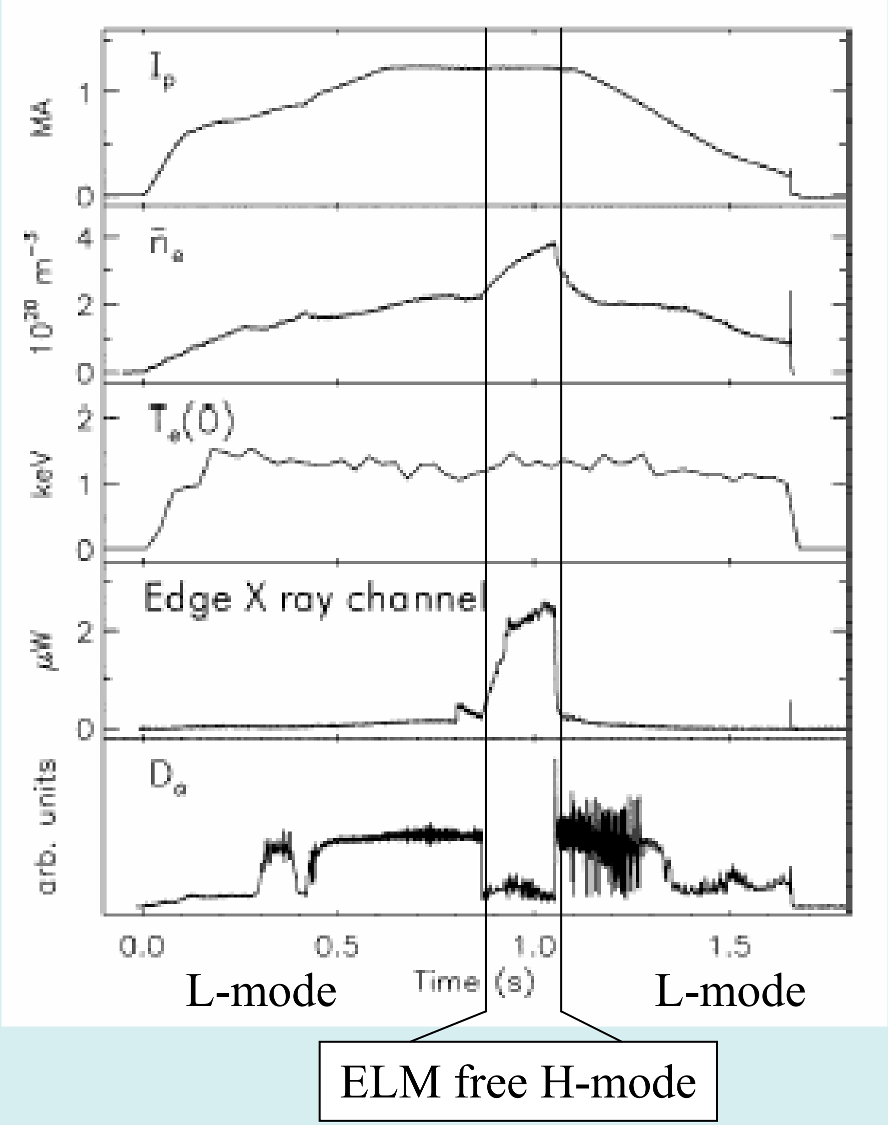
$$\Gamma_i^{neo} = -Z\Gamma_z^{neo} = -\frac{n_i D}{2}\left[K\left(\frac{1}{n_i}\frac{dn_i}{dr} - \frac{1}{Zn_z}\frac{dn_Z}{dr}\right) + \frac{H}{T_i}\frac{dT_i}{dr}\right]$$

K and H are the function of dimensionless parameters including the ion collisionality.

H is negative for the banana regime and positive for the PS regime.

What is observed in different machines in H mode plasmas

- During the H mode there is an increase of the soft X ray emission indicating an increase of impurity quantity inside the ETB

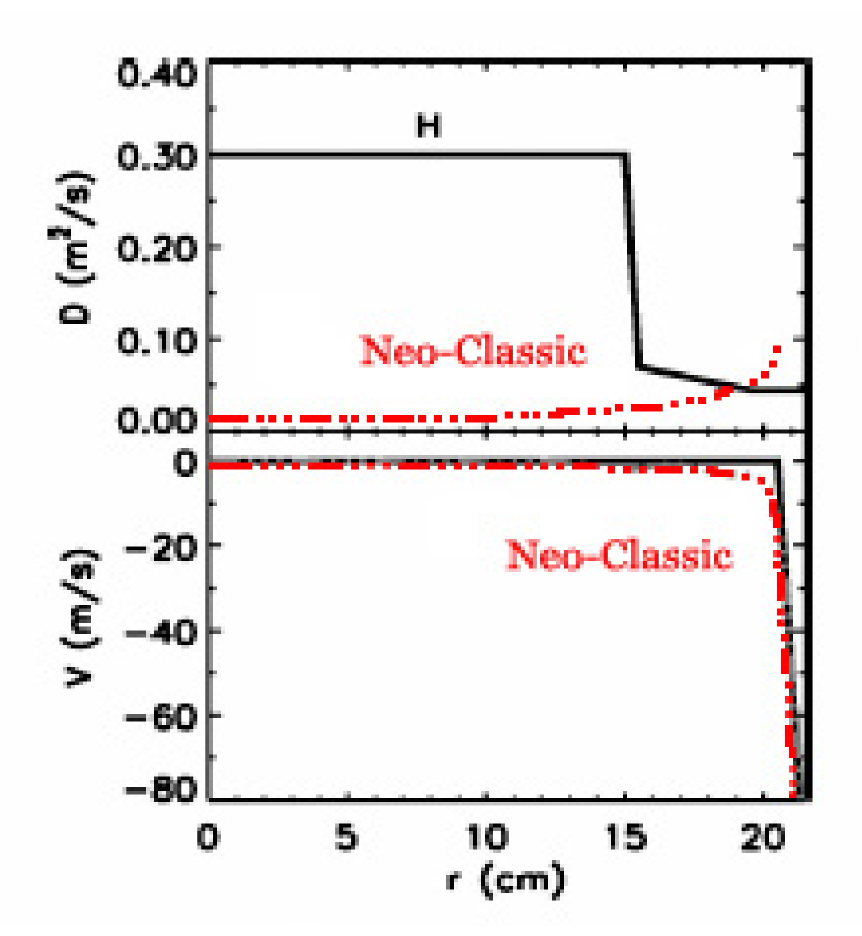


(**ALCATOR C-MOD**: Sunn Pedersen, T., *et al*, Nuclear Fusion, 40 (2000), 1795)

INSTITUTO SUPERIOR TÉCNICO

Transport coefficients in ELM free periods

- Multiple Ionization State Transport (MIST) code is used for the calculations of all impurity charge states
- A high experimental inward convective velocity described by the neoclassical convective velocity within the ETB
- Particle diffusion of the order of the neo-classical transport within the ETB



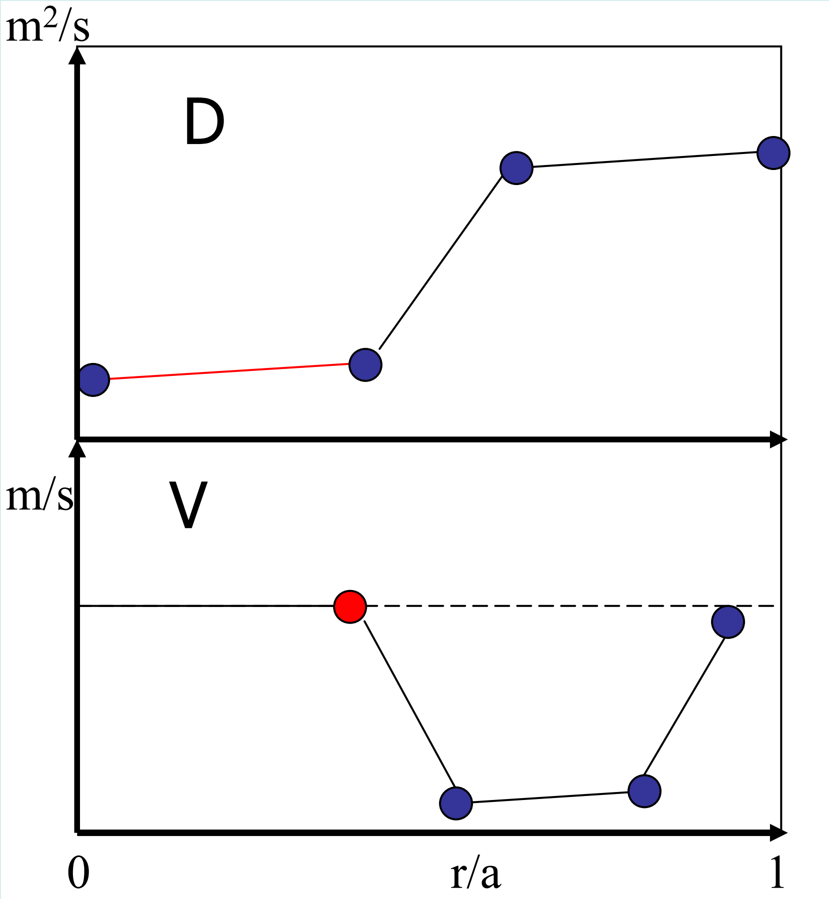
(**ALCATOR C-MOD**: Rice, J. E., *et al*, Physics of Plasma, 4 (1997), 1605)

How is impurity transport determined experimentally

Predictive approach: SANCO/STRAHL/MIST

- **11/2D transport code:**
  - Te(r,t), Ne(r,t) : need to be very accurate
  - Equilibrium: EFIT
  - D(r), V(r)
  - external source of neutral particle
  - Atomic physics to describe all sources and sinks: ADAS or others.
  - => Get impurity ion densities nz,i(r,t)

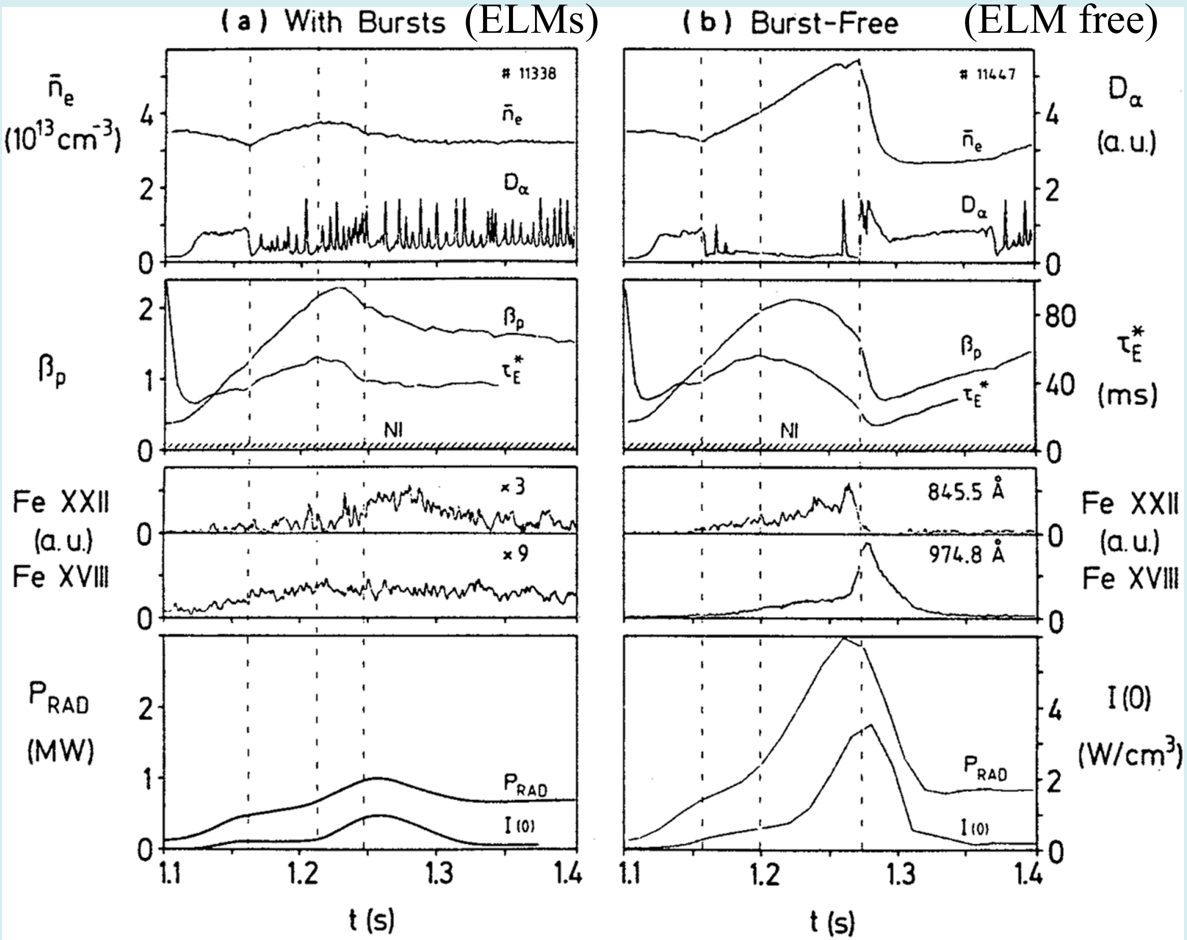
- **Determine D and V by reproducing spectroscopic measurements.**



INSTITUTO SUPERIOR TÉCNICO

The influence of the ELMs on the impurities

- An increase of impurity concentration in the plasma core that lead to radiative collapse
- Was observed a positive effect on impurity quantity in the plasma core

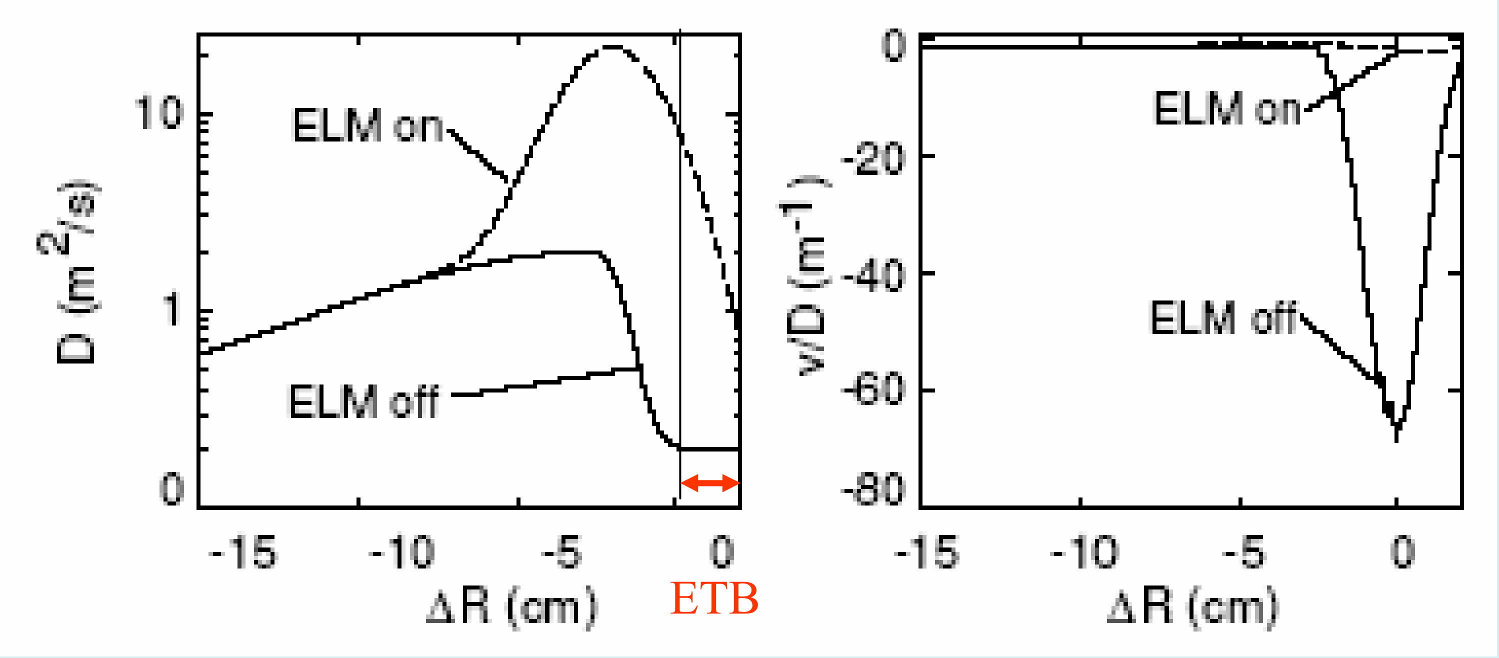


(**ASDEX:** M. Keilhacker, *et al*, Plasma Phys. Contr. Nuclear Fusion Research 1984, Vol. 1, 71-85, Viena, 1984 IAEA)

INSTITUTO SUPERIOR TÉCNICO

Transport coefficients during the ELM

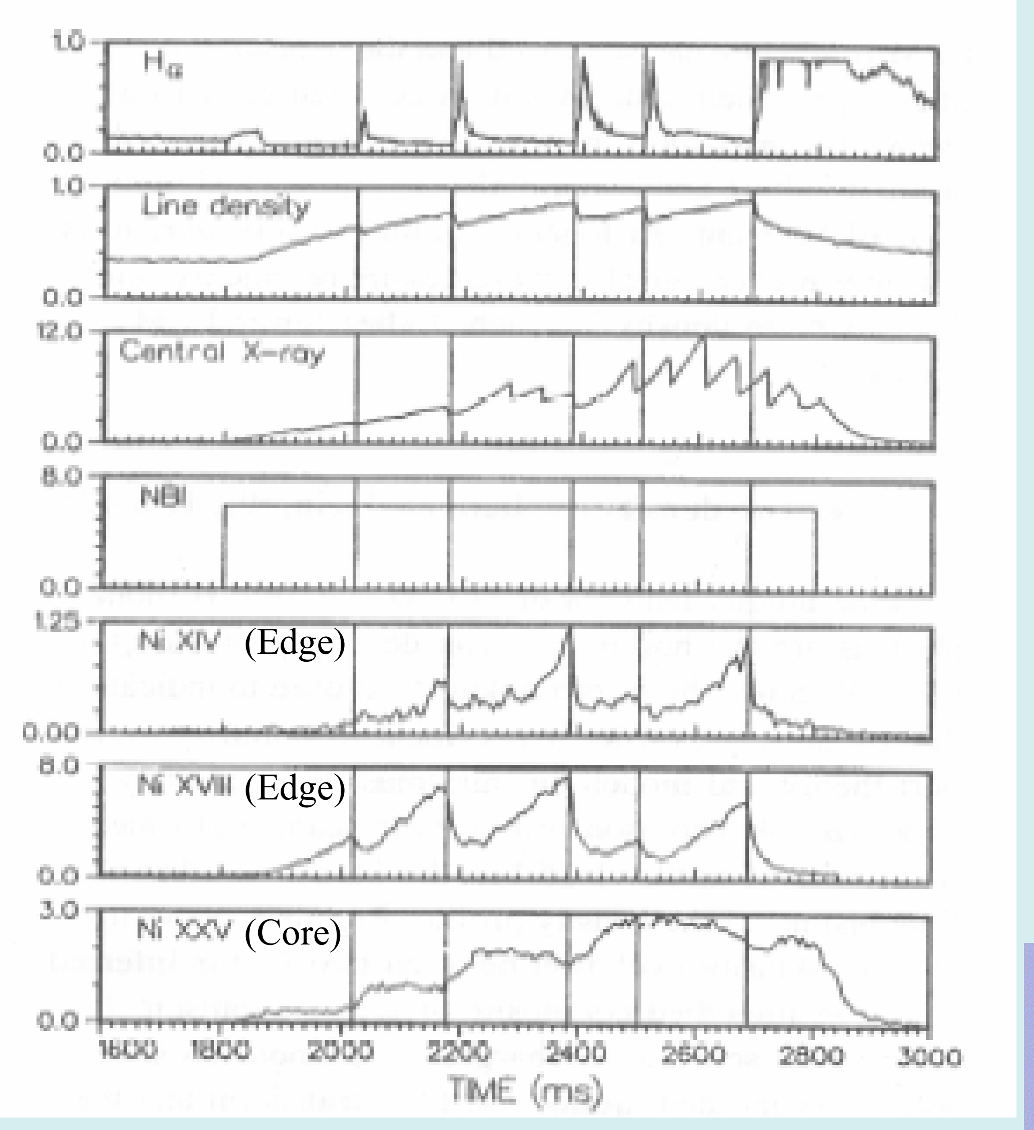
- The perturbed ELM region is greater then the ETB
- The effect of the ELM on impurities is like an increase of the diffusion within the perturbed ELM region



(**ASDEX UPGRADE**: D. Dux, *Impurity Transport in Tokamak Plasmas,* Thesis, June 2004)

The influence of the ELMs on the impurities

- The nickel signals are modulated with the ELMs
- Nickel concentration increases between the ELMs
- Impurities are removed from the ELM perturbed region not only to the SOL but also to the plasma core
- ELMs do not avoid impurity accumulation in the plasma core

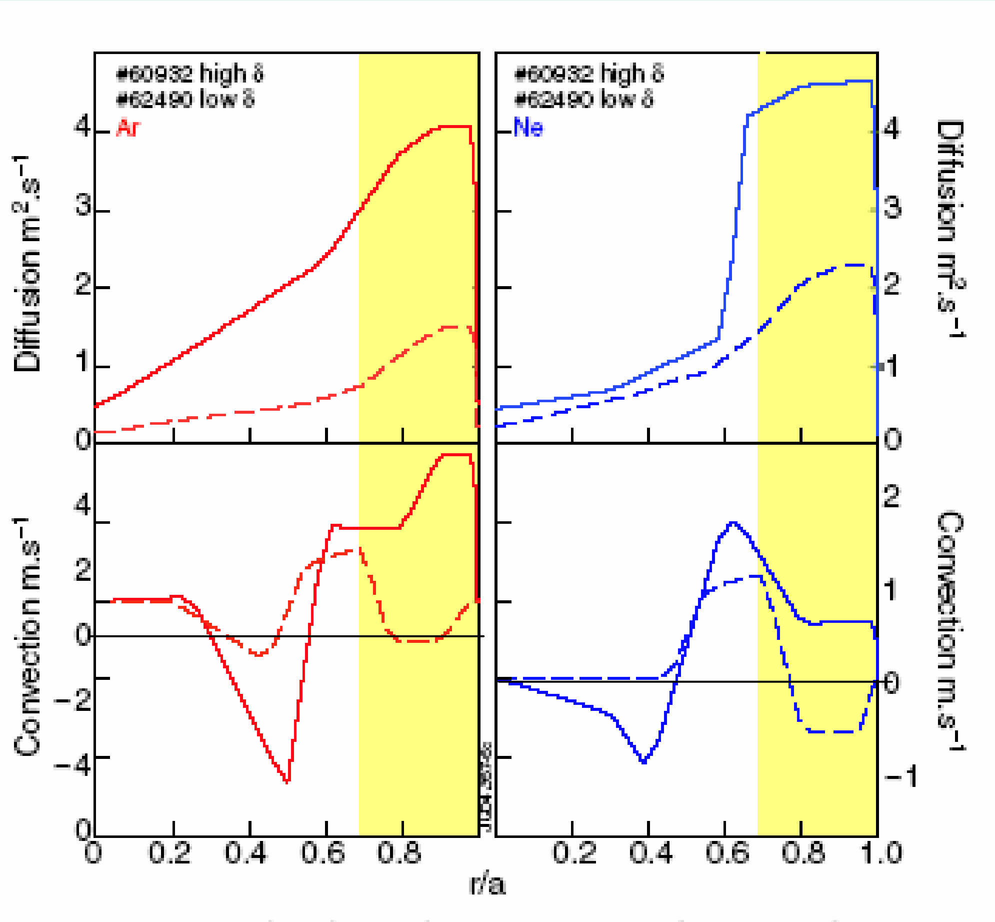


(DIII-D: M.E. Perry *et al*, Nuclear Fusion, 31 (1991), 1859)

Impurity quantity control inside the barrier (r/a<0.9)

Outward Convective velocity

- A outward directed convective velocity within the ETB was observed in some of JET ELMy H mode plasmas.



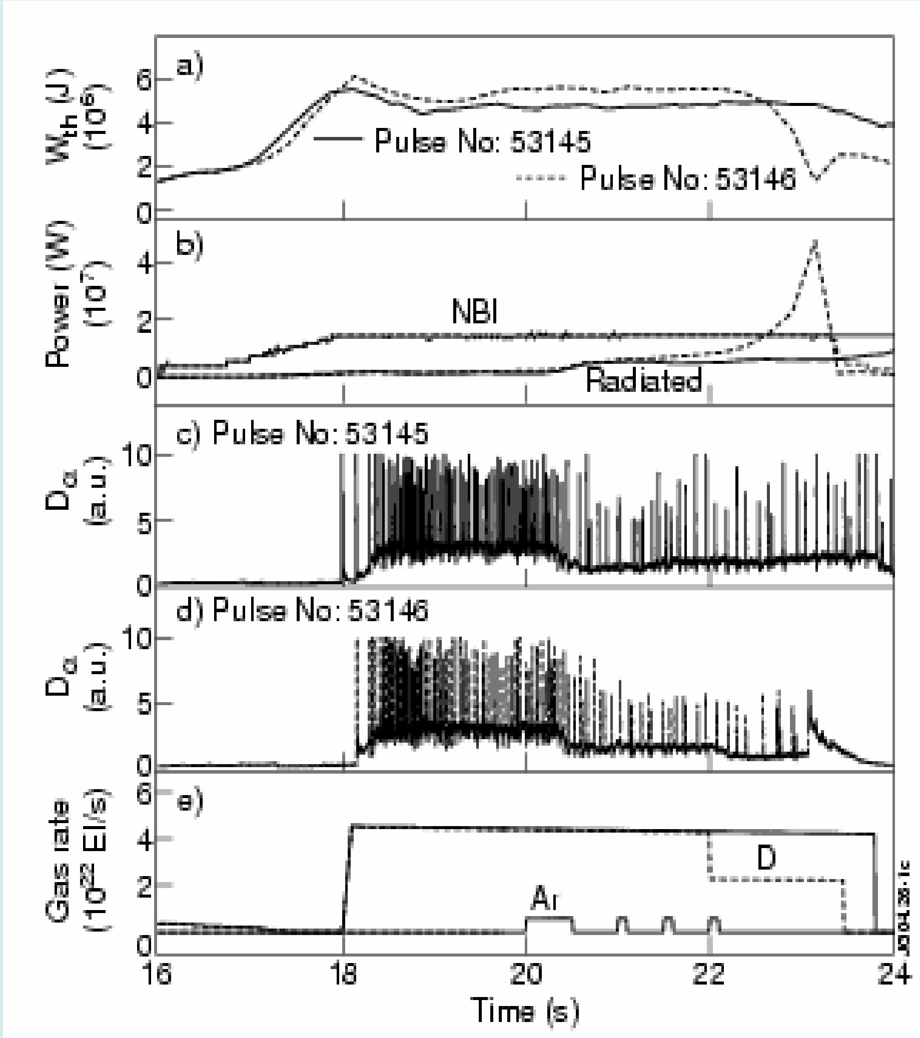
(JET: Giroud, C., *et al*, Proc. of the 31st EPS Conf. on Contr. Fus. and Plasma Phys., London, 2004),

INSTITUTO SUPERIOR TÉCNICO

Impurity quantity control inside the barrier (r/a<0.9)

Gas puff

- "the W concentration is strongly reduced by changing the edge parameters through the gas puff" (ASDEX UPGRADE: R. Neu, et al, Nuclear Fusion, 45 (2005) 209).
- An increase of the radiated power after the reduction of the gas puff was observed in JET plasmas



INSTITUTO SUPERIOR TÉCNICO

Modelling the Effect of the ETB on the impurity transport using JETTO/SANCO

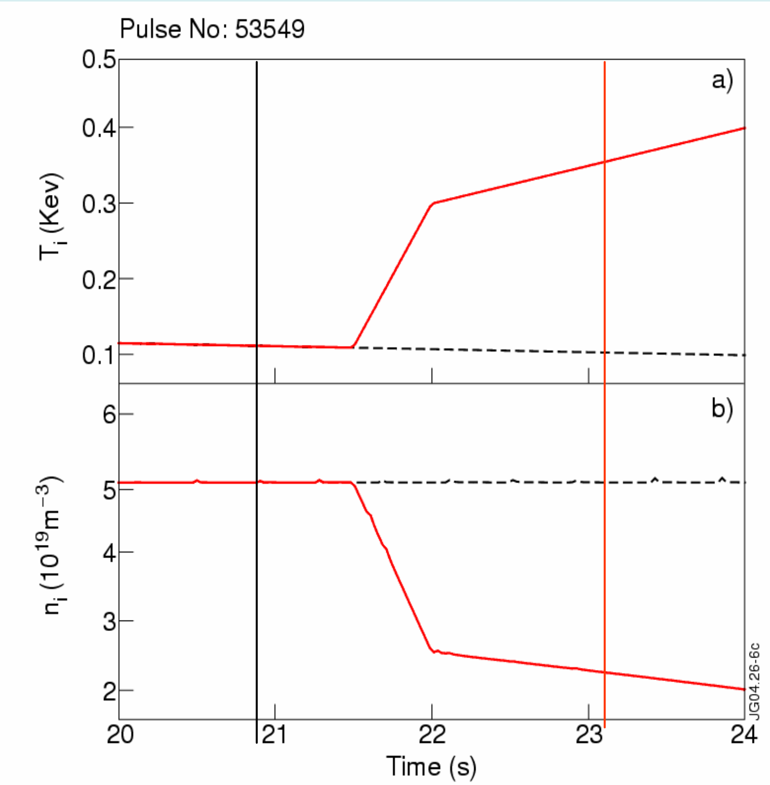
- SANCO solves a set of continuity equations for all ionisation stages of up to two impurity species
- SANCO takes all transport coefficients from JETTO.
- Neoclassical Impurity Transport within the ETB (if the transport is neo-classical)

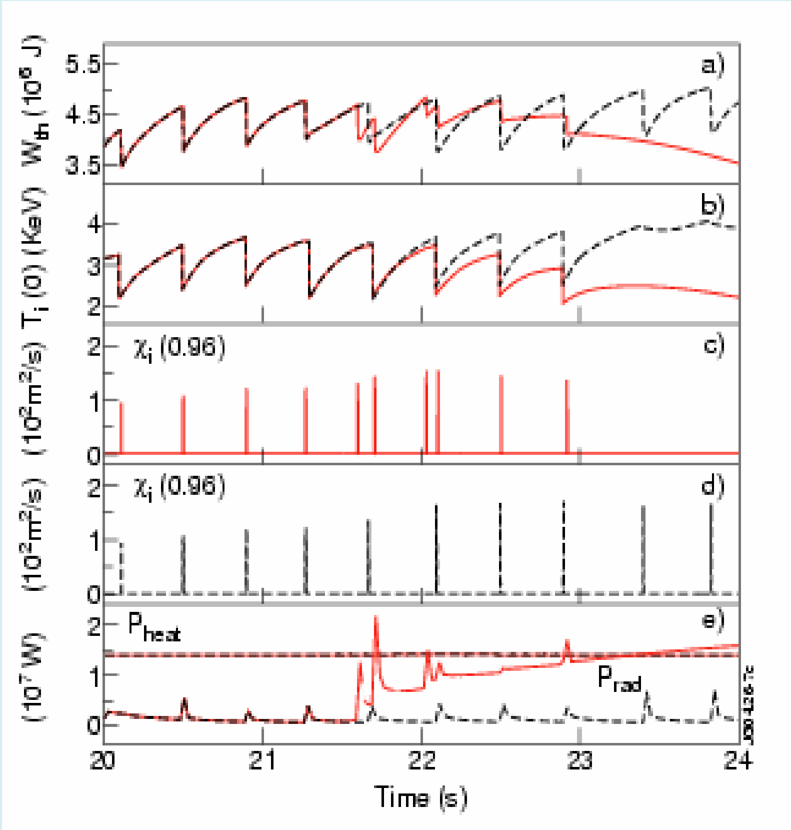
$$\Gamma_i^{neo} = -Z\Gamma_z^{neo} = -\frac{n_i D}{2}\left[K\left(\frac{1}{n_i}\frac{dn_i}{dr} - \frac{1}{Zn_Z}\frac{dn_Z}{dr}\right) + \frac{H}{T_i}\frac{dT_i}{dr}\right]$$

- Anomalous Transport; for this simulations we considered the Bohm/gyroBohm model

Modelling the Effect of the ETB on the impurity transport using JETTO/SANCO (2)

- Two sets boundary conditions: one simulates a continuous gas puff and the other its decrease (J-S Lonnroth, 2003)

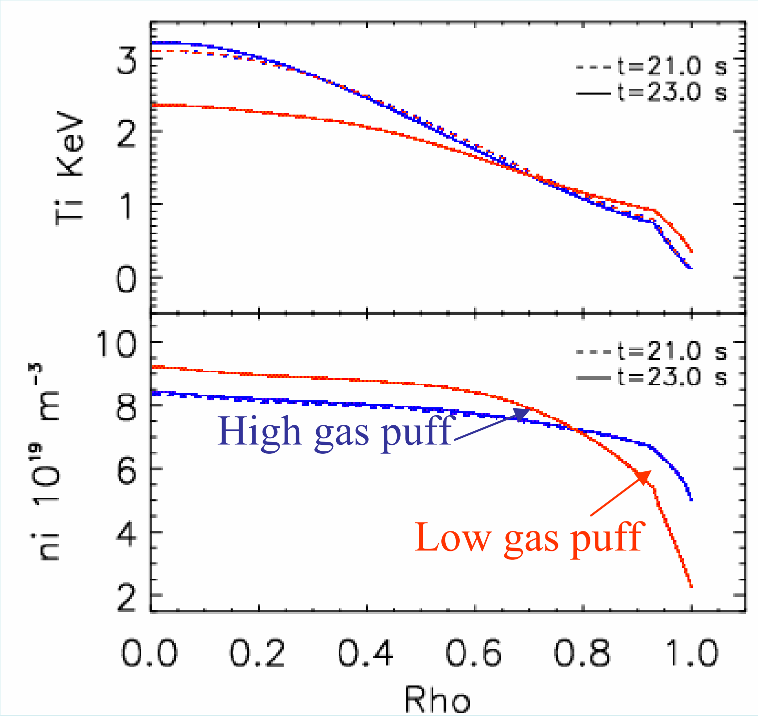


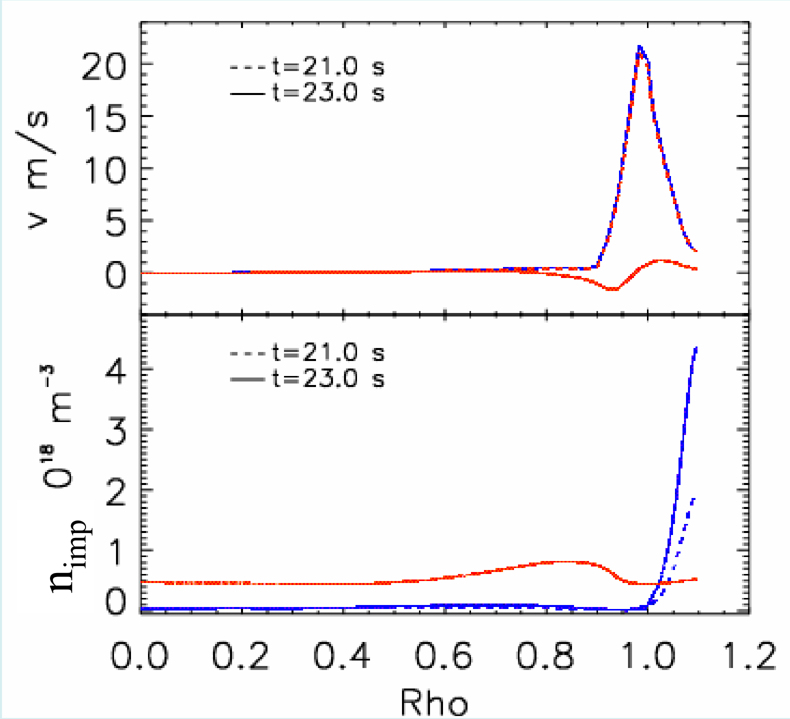


INSTITUTO SUPERIOR TÉCNICO

Modelling the Effect of the ETB on the impurity transport using JETTO/SANCO (3)

- The neo-classical convective velocity within the ETB changes from inward- to outward-directed .
- The impurity density inside the top of the barrier increases when the sign of the convective velocity changes





$$\Gamma_i^{neo} = -Z\Gamma_z^{neo} = -\frac{n_i D}{2}\left[K\left(\frac{1}{n_i}\frac{dn_i}{dr} - \frac{1}{Zn_Z}\frac{dn_Z}{dr}\right) + \frac{H}{T_i}\frac{dT_i}{dr}\right]$$

INSTITUTO SUPERIOR TÉCNICO

Modelling the Effect of the ETB on the impurity transport using EDGE2D/NIMBUS

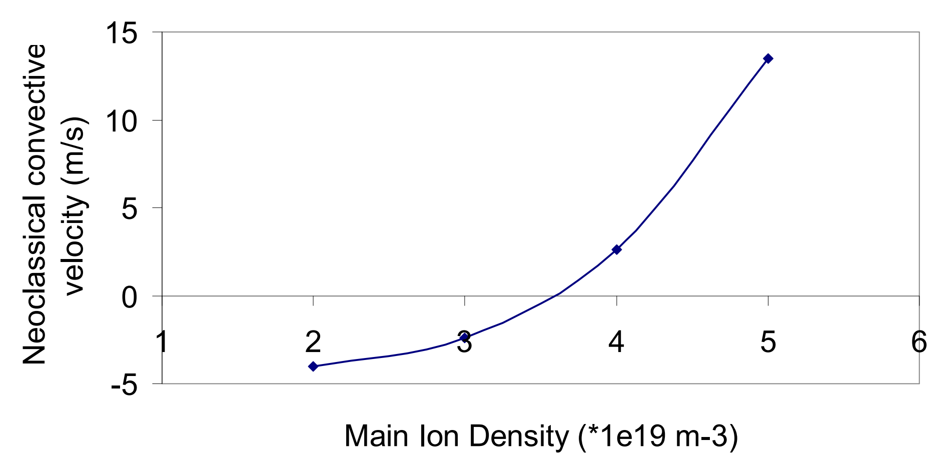
- EDGE2D is a 2D code that solves numerically the impurity transport in the SOL.
- EDGE2D is coupled to NIMBUS, which is a Monte-Carlo code, calculating the particle and energy sources due to neutrals recycled from the targets and chamber walls.

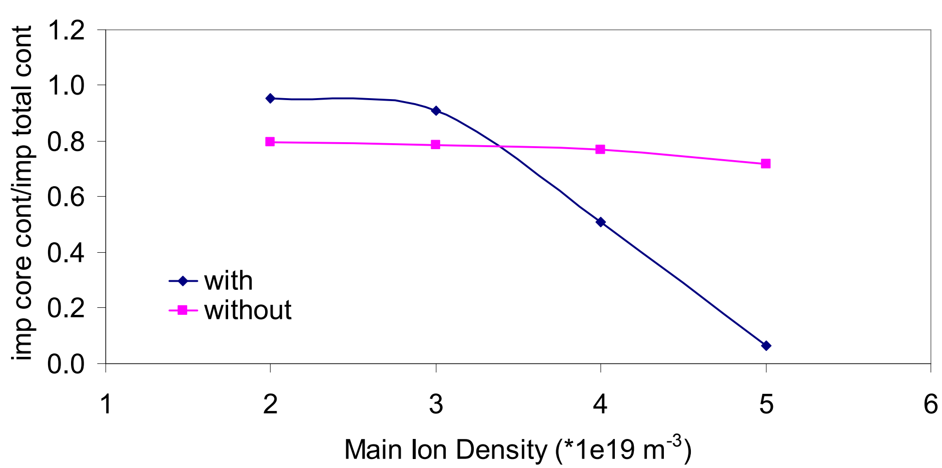
- The perpendicular transport was determined from JETTO simulations for all particles
- Parallel transport is classical in EDGE2D approximation
  - The parallel anomalous convective velocity was not considered.

EUROPEAN FUSION DEVELOPMENT AGREEMENT

Modelling the Effect of the ETB on the impurity transport using EDGE2D/NIMBUS (2)

- Neoclassical convective velocity within the ETB calculated with NCLASS for different main ion densities at the outer mid plane separatrix
- The increase of the main ion gas contributes to prevent the impurity accumulation not only because the friction force increases in the SOL but also because the neoclassical convective velocity changes from inward to outward direction

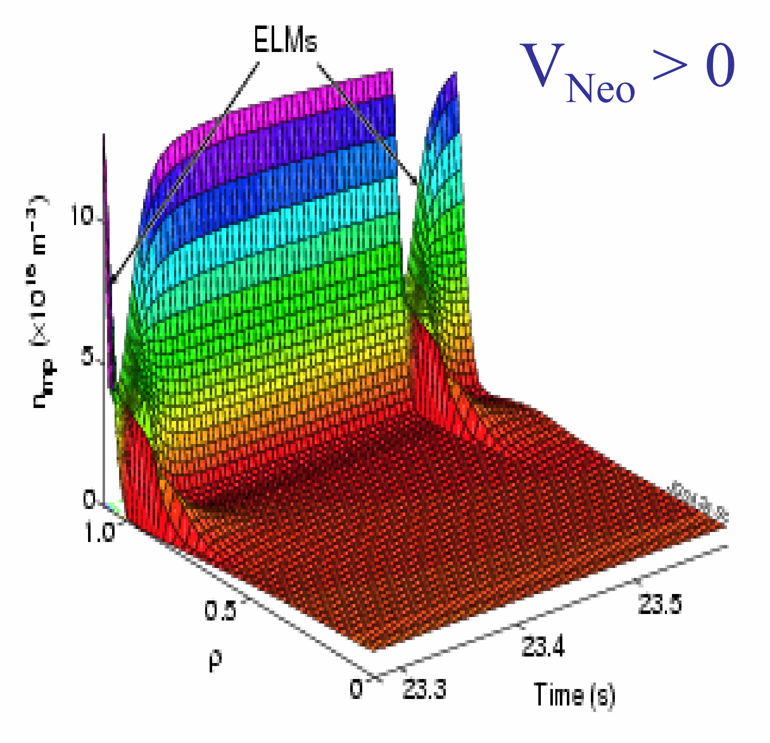


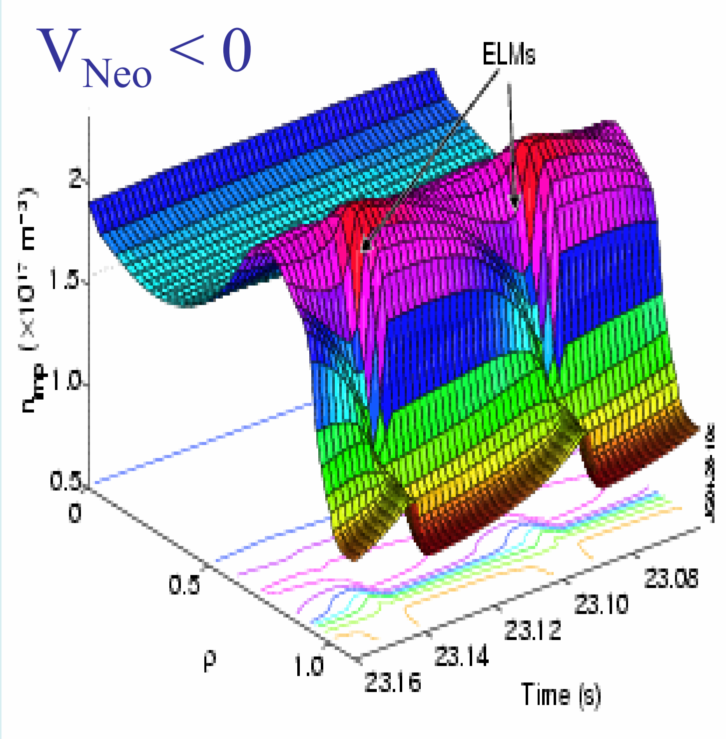


INSTITUTO SUPERIOR TÉCNICO

Modelling the ELMs influence on impurities using JETTO/SANCO

- In JETTO/SANCO the ELM is simulated by increasing the anomalous diffusion within the ETB
- The impurities recover their profiles in 50 ms after the ELM, in impurity seed plasmas the time between type I ELMs is typically around 200 ms

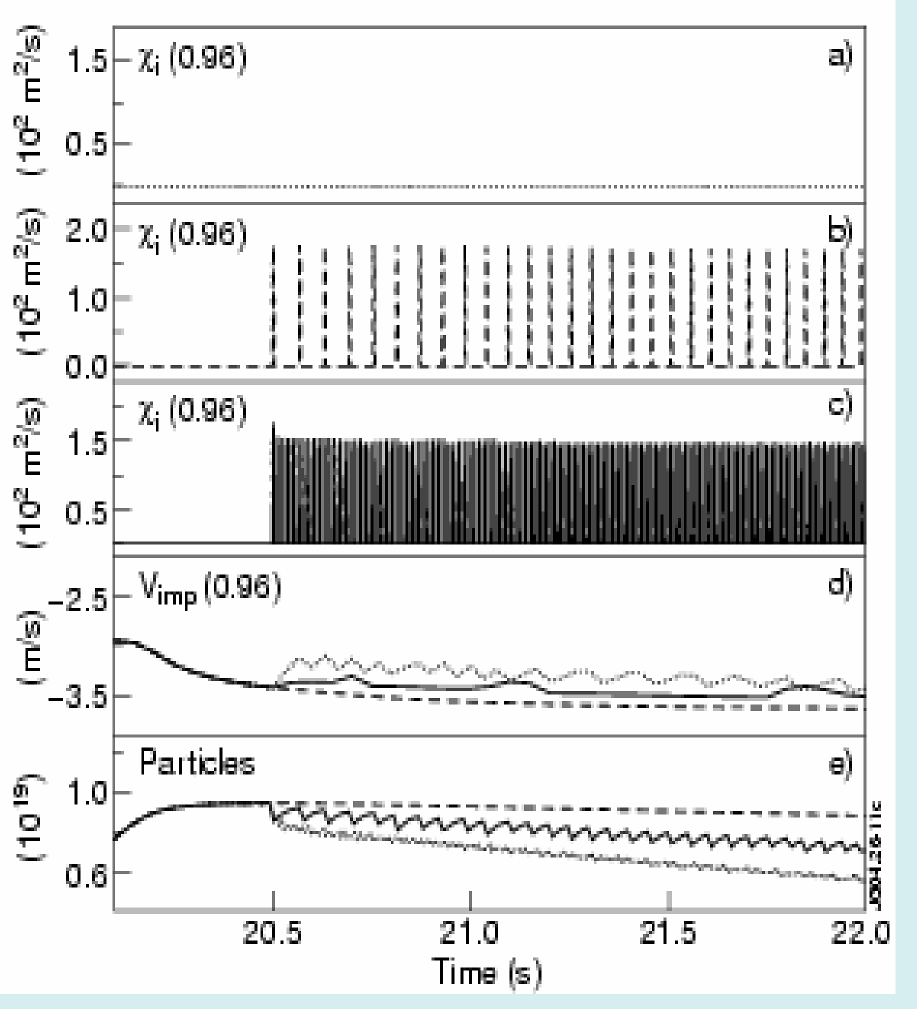




Modelling the ELMs influence on impurities using JETTO/SANCO (2)

- $V_{Neo} < 0$
- The higher is the ELM frequency less impurities particles are in the plasma core.

The influence of the neoclassical convective velocity between has a greater influence on the impurity quantity in the plasma core than the ELMs



INSTITUTO SUPERIOR TÉCNICO

Conclusions

- **It is experimentally observed that:**
  - ➢ The impurity accumulation has been observed in all tokamaks and it is due to a inward convective velocity (at the level of the Neo-classical) between ELMs
  - ➢ The ELMs remove impurities from the perturbed ELM region (but not necessary out of the plasma)
  - ➢ NOT only ELMs was observed to reduce the impurity quantity on the plasma core:
    - ✓ An convective velocity outward directed in JET H mode plasmas was also observed.
    - ✓ In ASDEX UP the W concentration was strongly reduced when high level of main ion gas puff was used.
    - ✓ An increase of the radiated power after a reduction of the gas puff.

Conclusions (2)

- **It is observed in the models that:**
  - The high level of gas puff prevents impurities reaching the plasma core because they are pushed towards the targets plates in the SOL and the neoclassical convective velocity in the ETB is outward directed.
  - The influence of the neoclassical convective velocity between ELMs has a greater influence on the impurity accumulation in the plasma core than the ELMs

(P.Belo *et al*, Plasma Phys. Control. Fusion, **46** (2004) 1299)