# *Impurity transport at the plasma edge in ASDEX Upgrade*

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# Overview

- Motivation
  - ⇨Can we predict the impurity content of an H-mode plasma?
  - ⇨Can we do it for W? – ASDEX Upgrade is a full-W device!
- Measurements of the pedestal transport – Z-dependent
- 1D Transport/Erosion Model for W – putting details together
- Application of Model to ITER
- Summary

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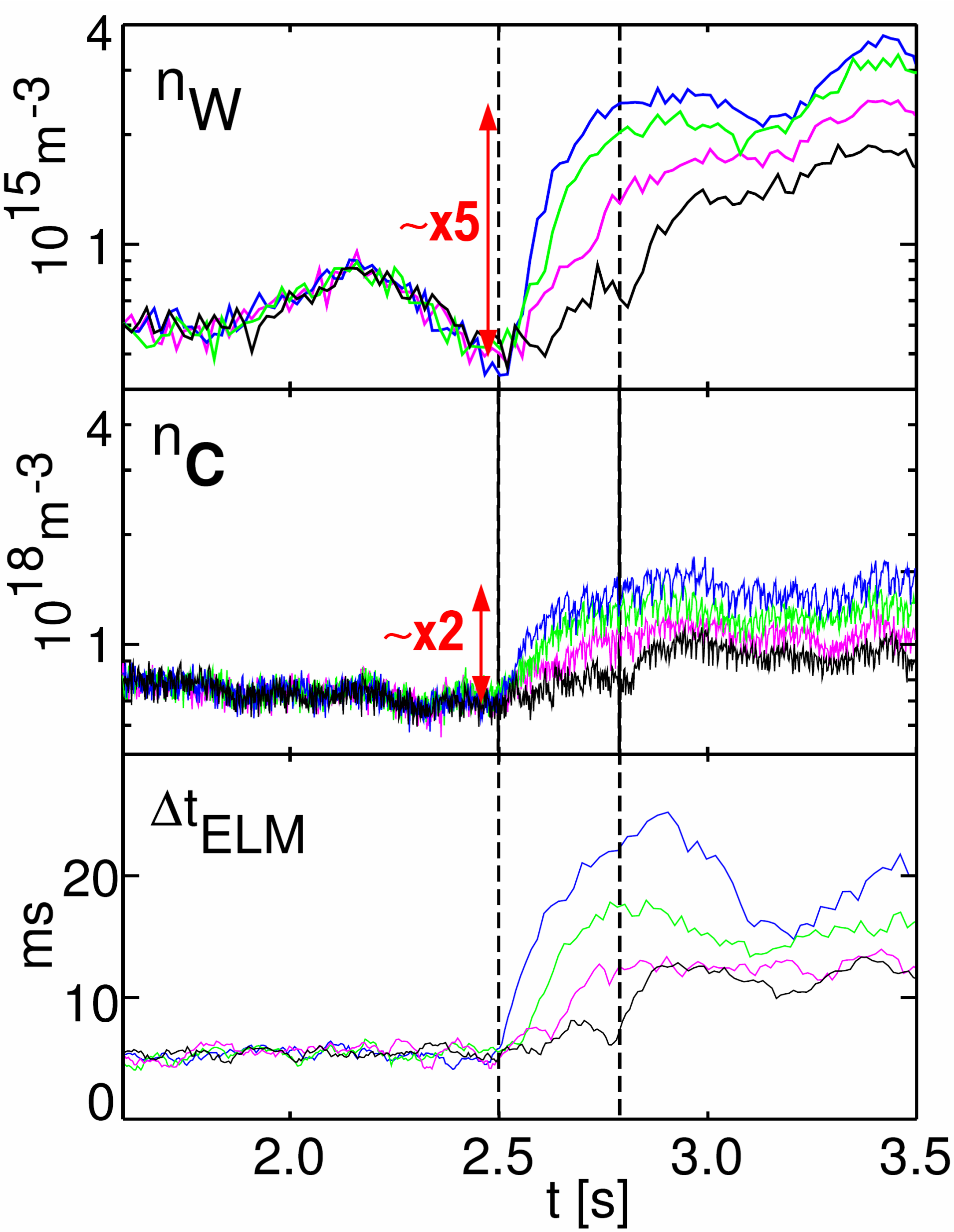
# W- and C-density pedestal vs. ELM frequ.




- Scan in D-puff rate changes ELM frequency
- Lower ELM frequency leads to more $n_W$ inside pedestal
- $n_C$ increases less strong with $\Delta t_{ELM}$ than $n_W$
- Need to know inter-ELM transport to understand effect of ELMs

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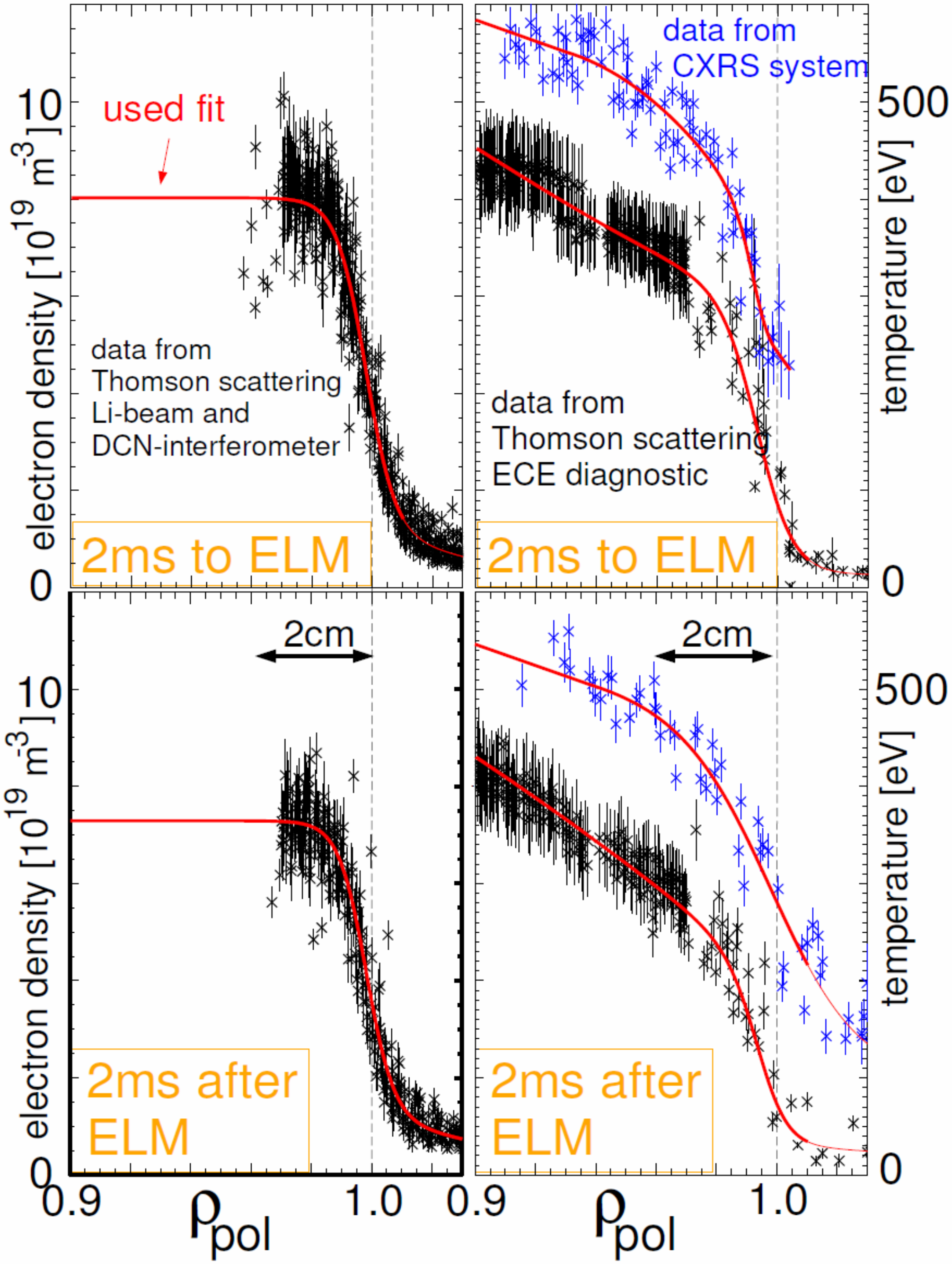
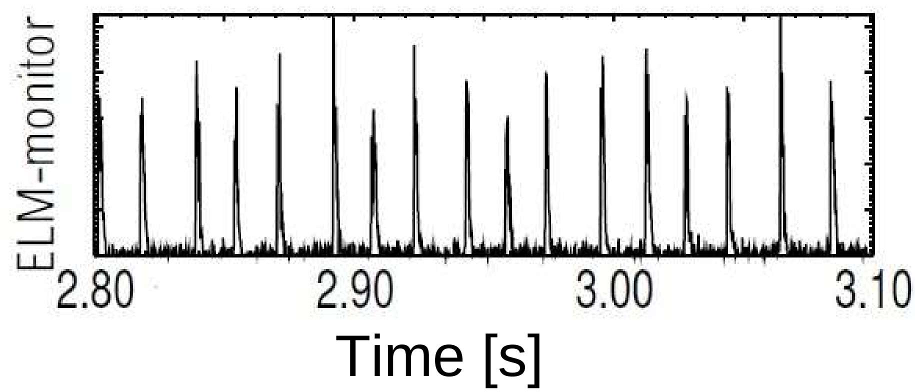
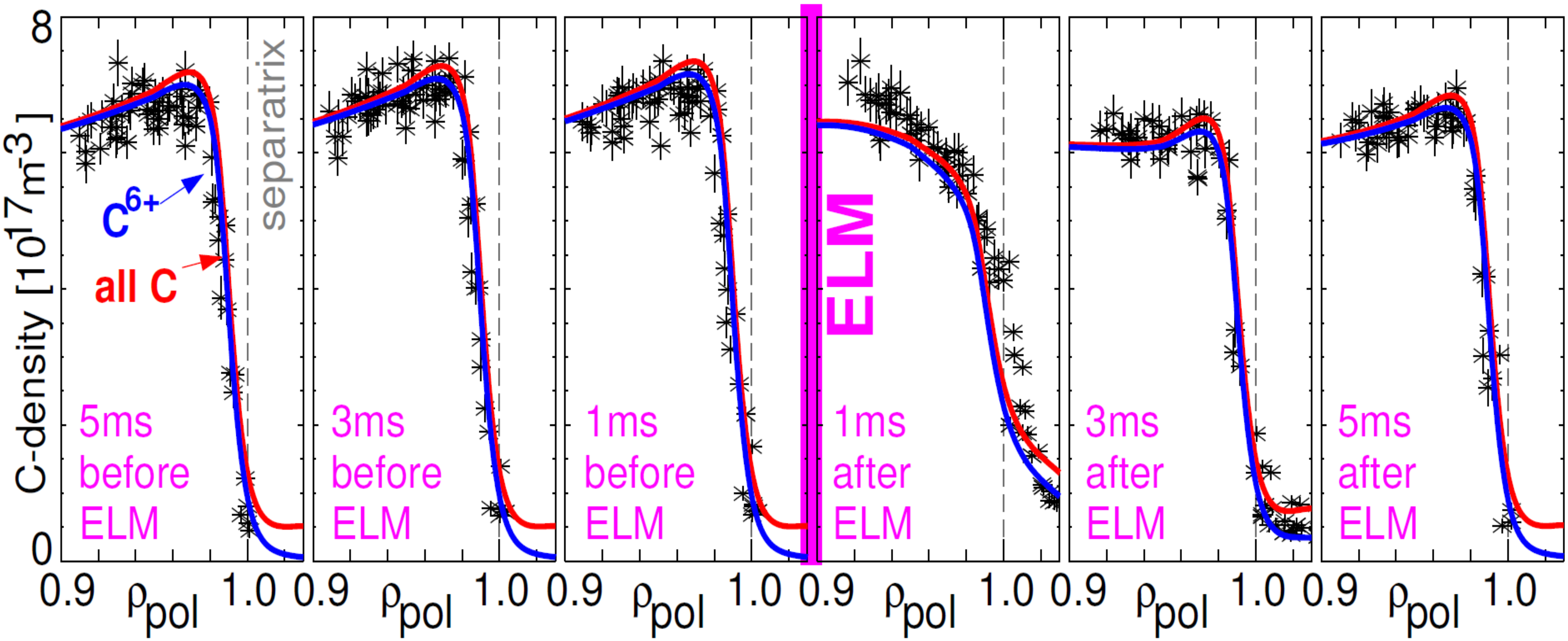
# Inputs for Modelling the Impurity Transport




- Electron profiles and Edge-CXRS system during type-I ELMy H-mode
- Profiles are adjusted by a two-point model for power balance (i.e. Te =85eV at separatrix)
- Analysis in inter-ELM phase



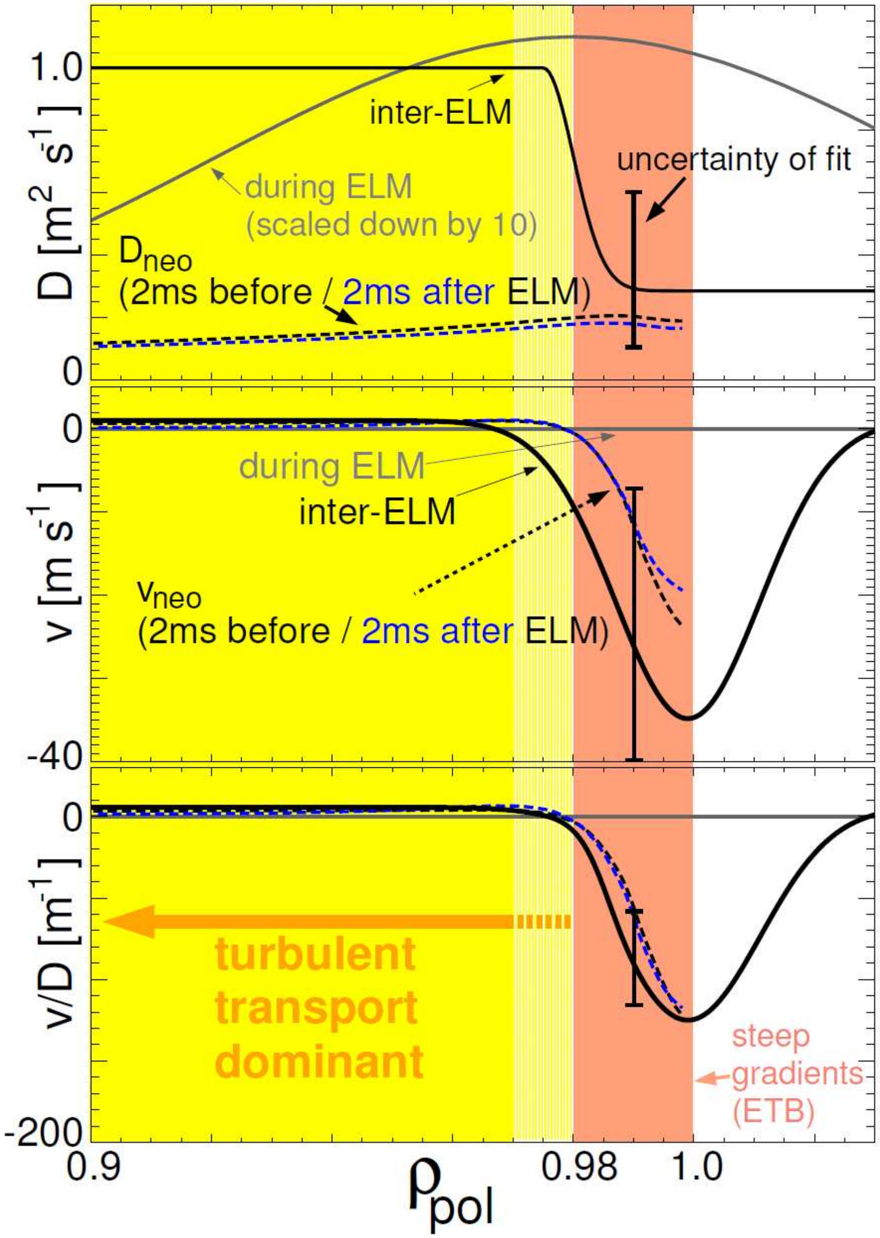
# Model finds good match for impurity profiles




- Profiles are well described, except 1ms after ELM (filaments, ELM-model)
- Pedestal in $C^{6+}$ is mainly due to pedestal in total C density
- Separation of v and D possible due to:

(1) modulation by ELM and (2) position of gradient

# Found v, D and v/D agree with Neoclassics



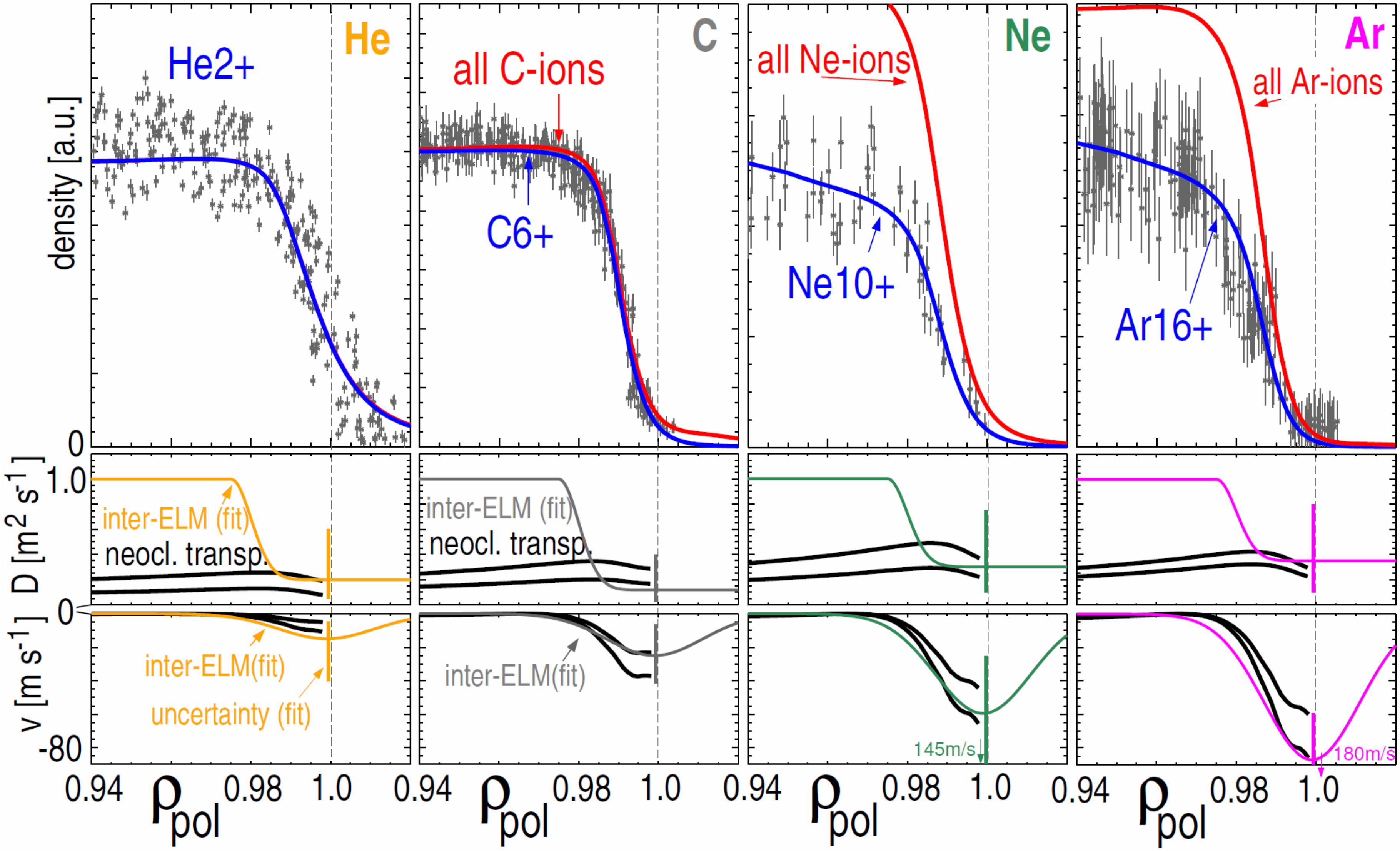

- D and v are separated, but with relative large uncertainties
- v/D is determined well by the gradients and the pedestal height, i.e. pedestal peaking factor

$$F = \frac{n_C(\rho_{pol} = 0.97)}{n_C(\rho_{pol} = 1.00)} = \exp\left( \int_{\rho_{pol}=1.00}^{\rho_{pol}=0.97} -\frac{v}{D}\, dr \right)$$

(In equilibrium, w/o sources)

- Neoclassical transport (NEOART) is matched for v/D, (NEOART is equivalent to NCLASS)
- Neocl. approximation valid for impurities; mostly PS, negligible banana, plateau contribution

# Neoclassical transport for He, C, Ne and Ar




- Impurity scan gives stronger inward convection for higher charge
- Implications: every impurity has a different gradient (steep for W!)

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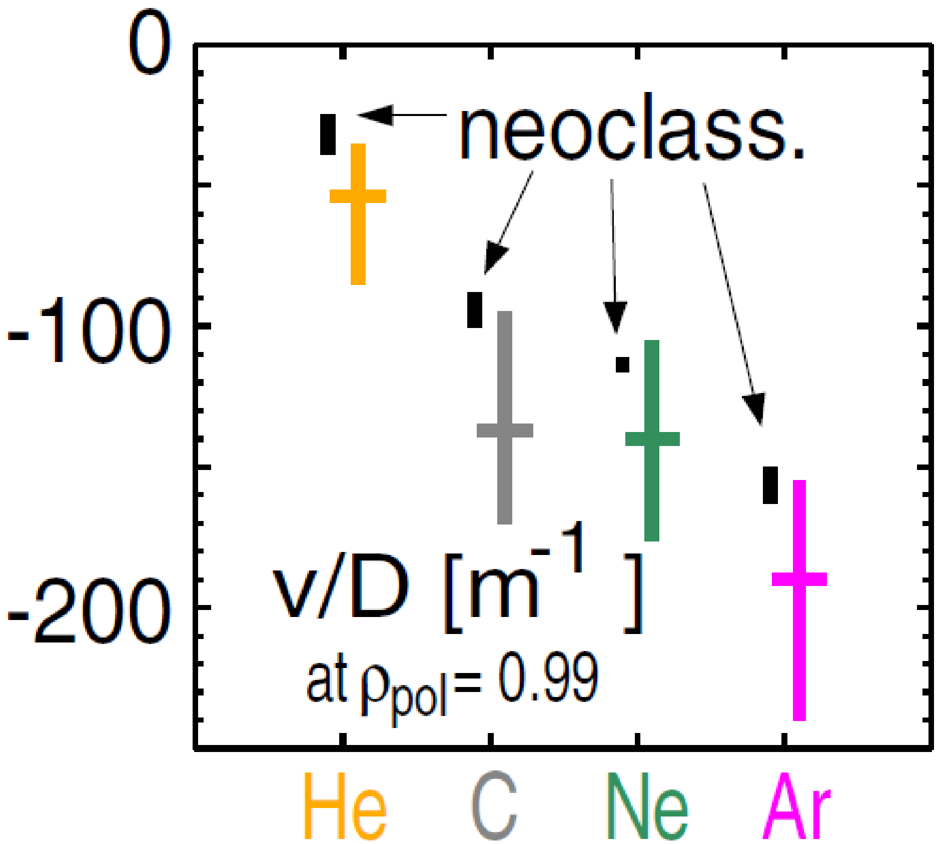


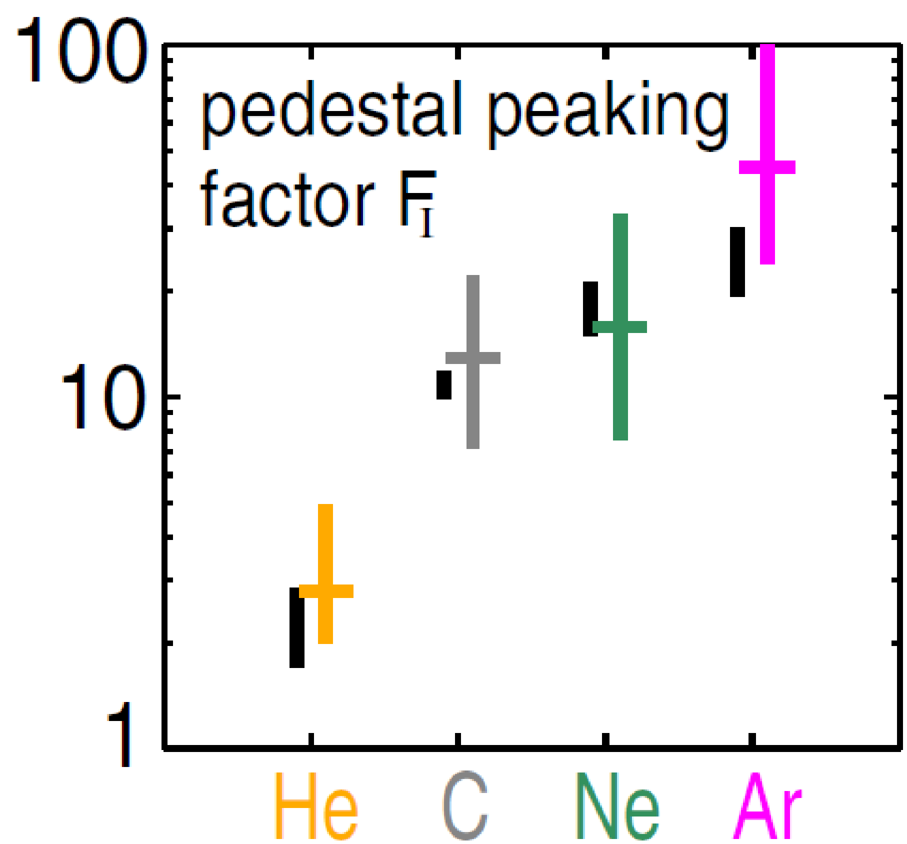


Consistently:

- v/D gets more negative for increasing Z
- the pedestal peaking factor $F_I$ increases with increasing Z

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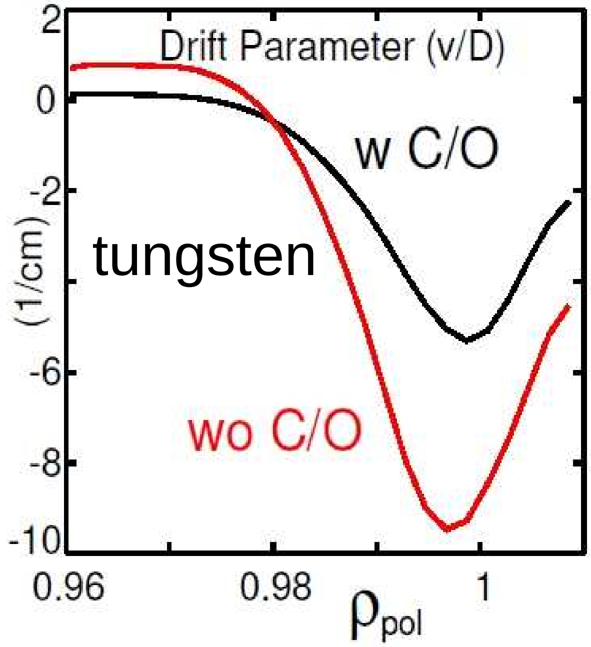
# 1D Transport Model and Wall Sputtering




- W-Transport at barrier depends on local impurity mix
- W-Wall erosion depends on impurity mix
- Plasma parameters determine also W-transport, W erosion and prompt deposition of W
- Parallel Transport in SOL modelled with constant Mach number

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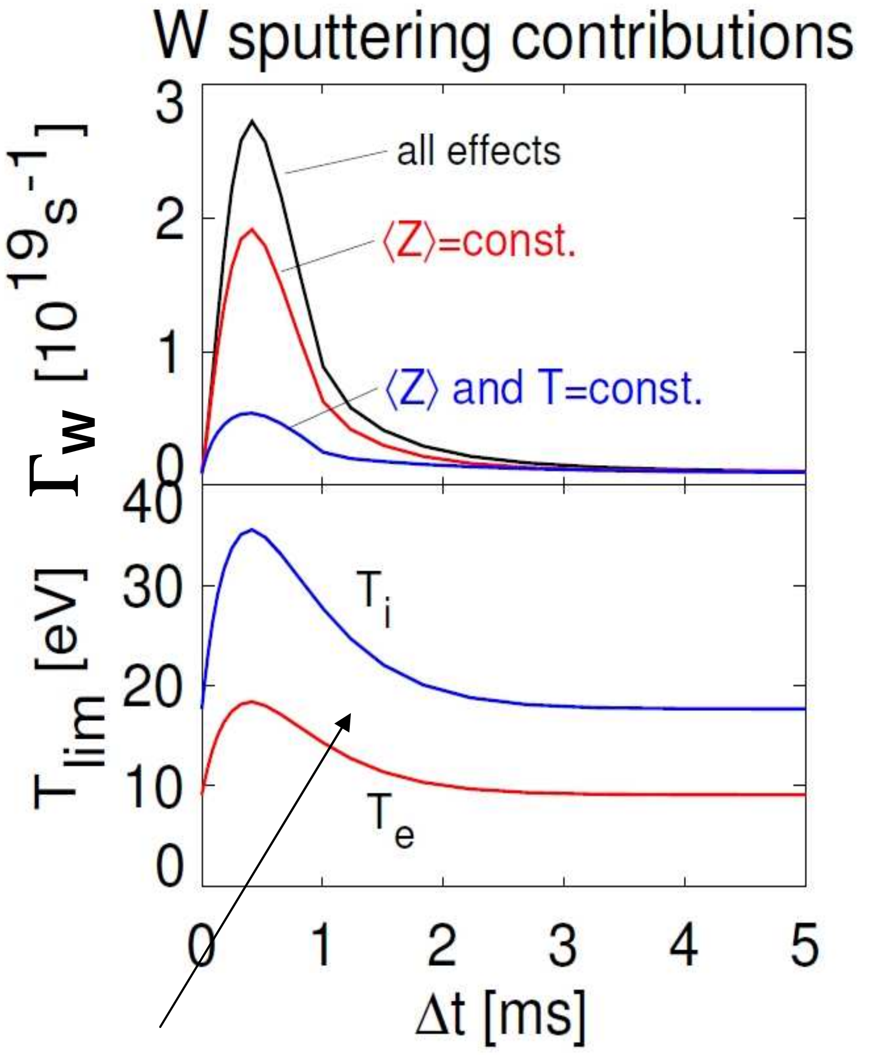


Measurements exhibit same magnitude

Kočan M., et. al., this conference, I-3

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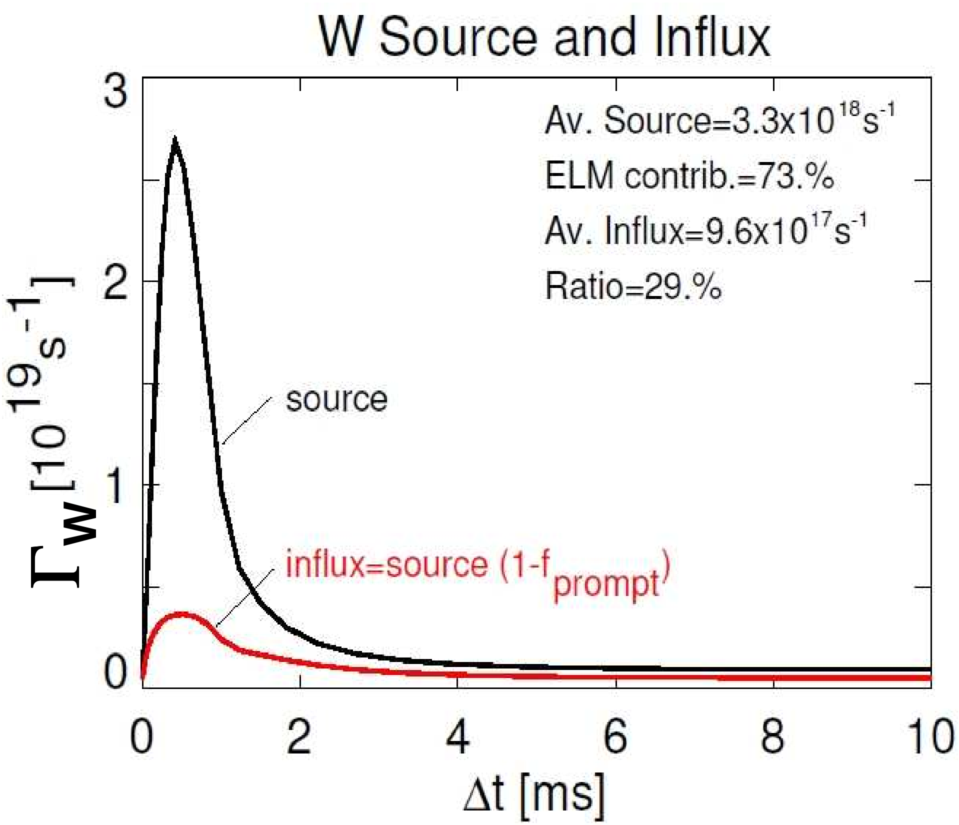
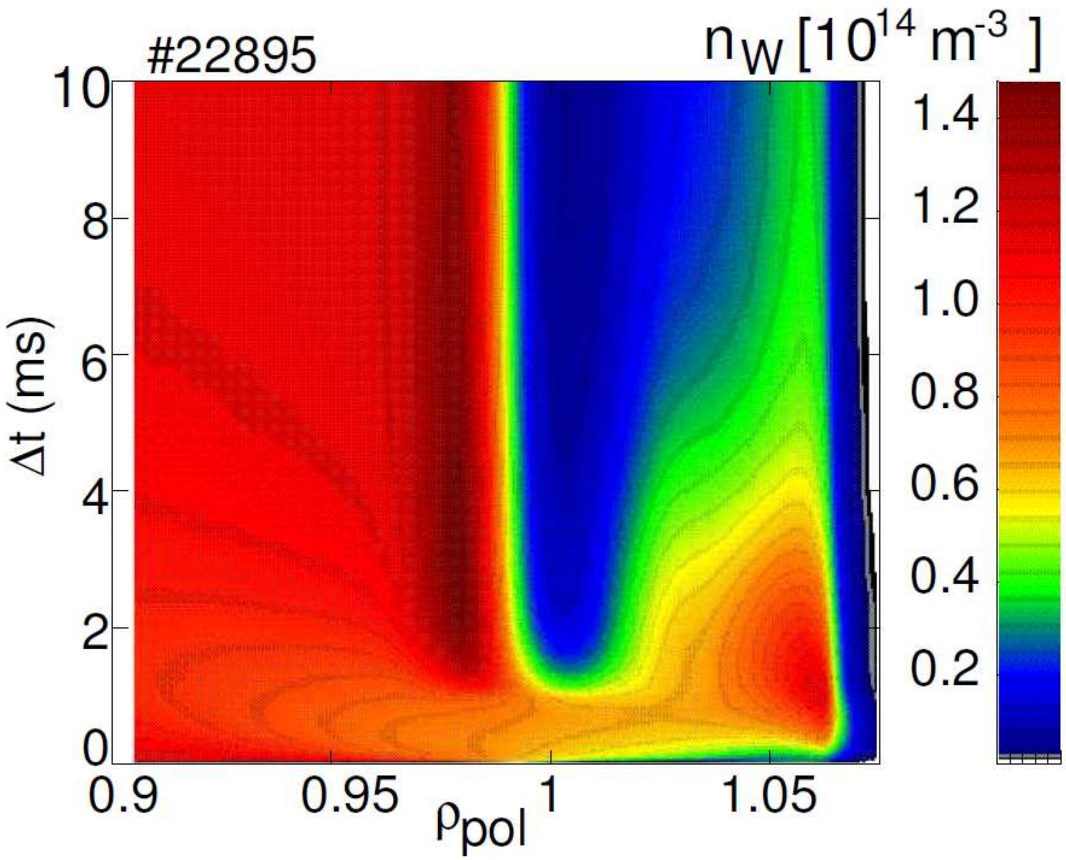
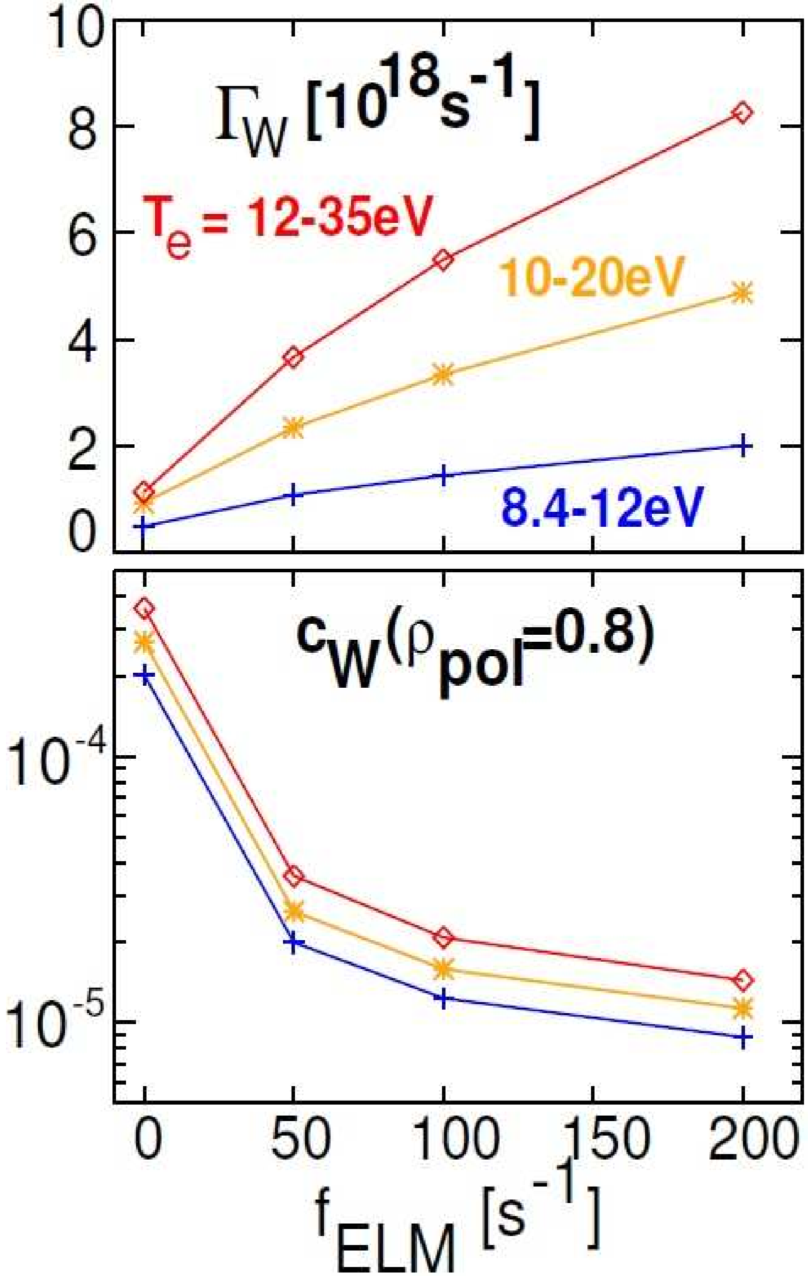


# W-density pedestal and ELM effects




- ELM flattens steep gradients
- ELM causes W erosion
- After ELM gradients steepen again
- Influx due to ELM 'refills' gradients very fast
- SOL cleans up (parallel transport!) and pedestal keeps building slowly

# Model Agrees with Experiment




- ELM frequency scan in model
- Small variations in model assumptions allow to vary influx of W
- ELM flushing dominates ELM source

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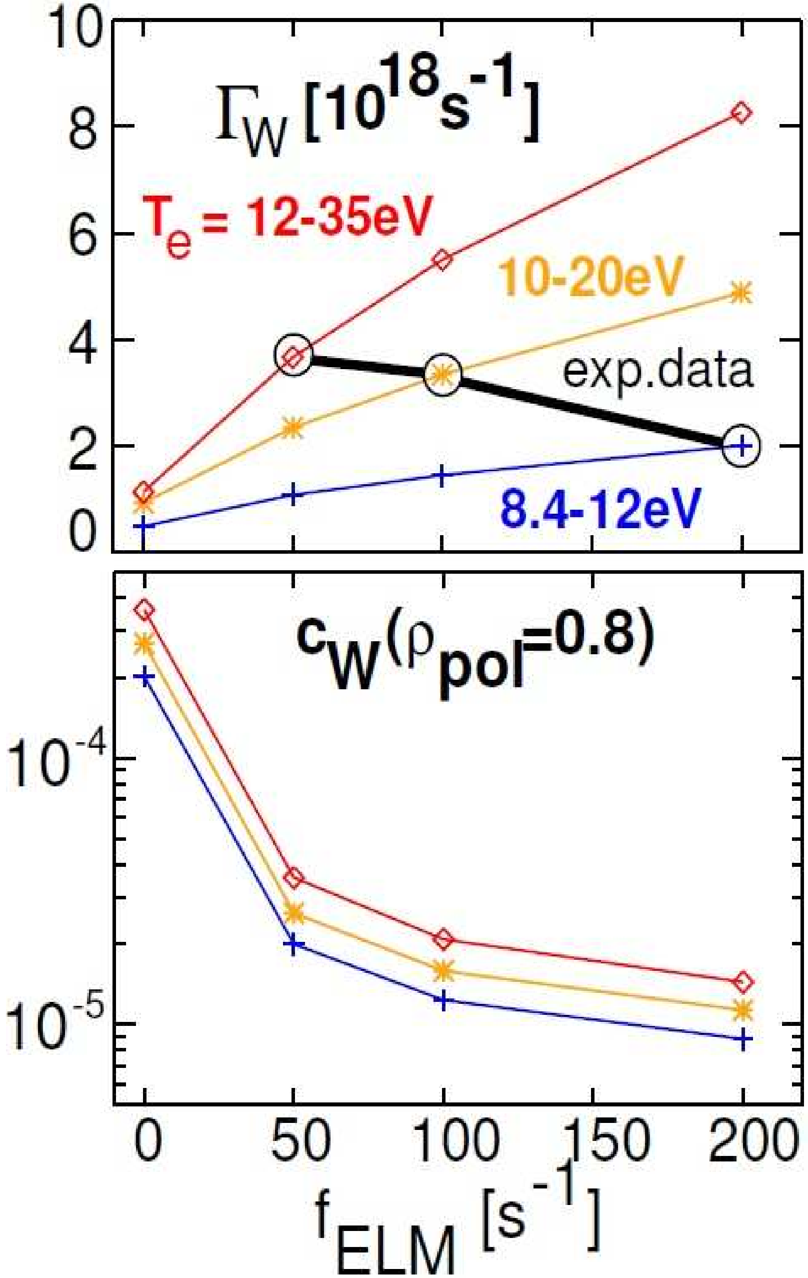


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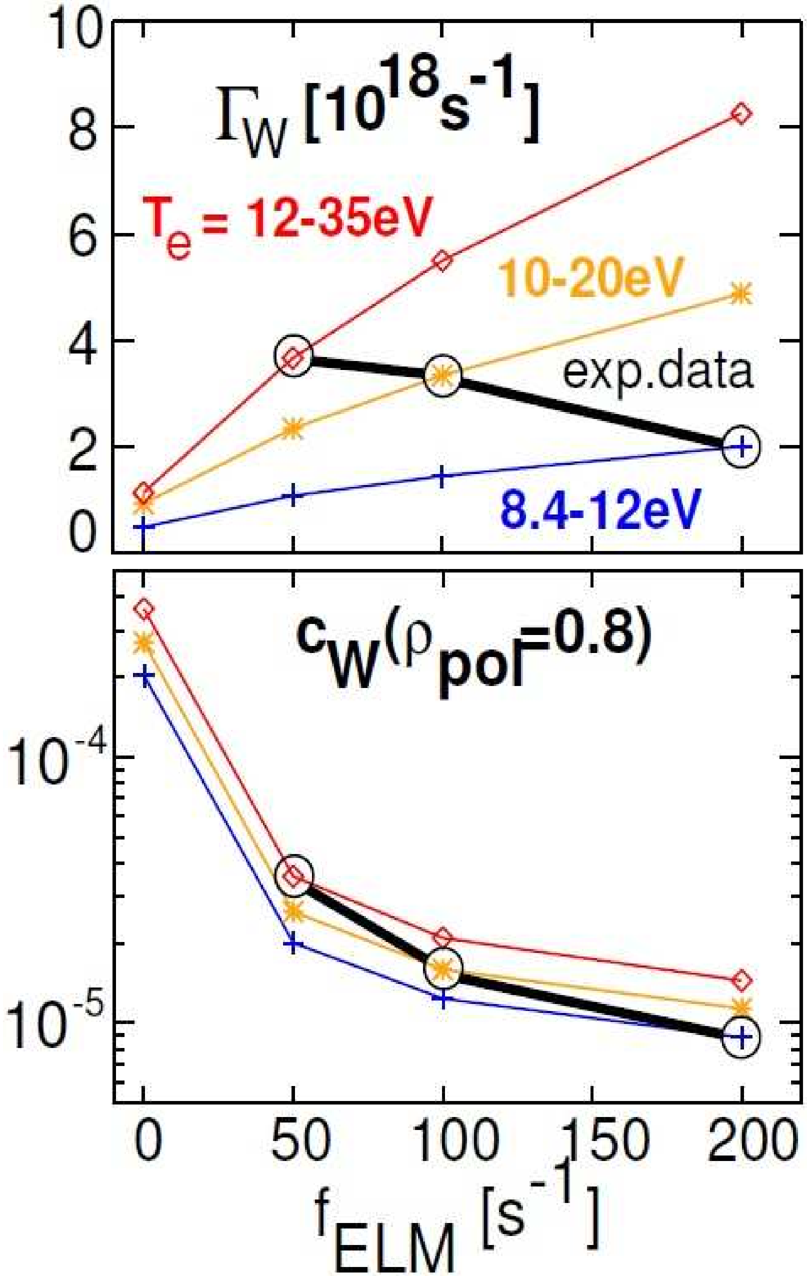


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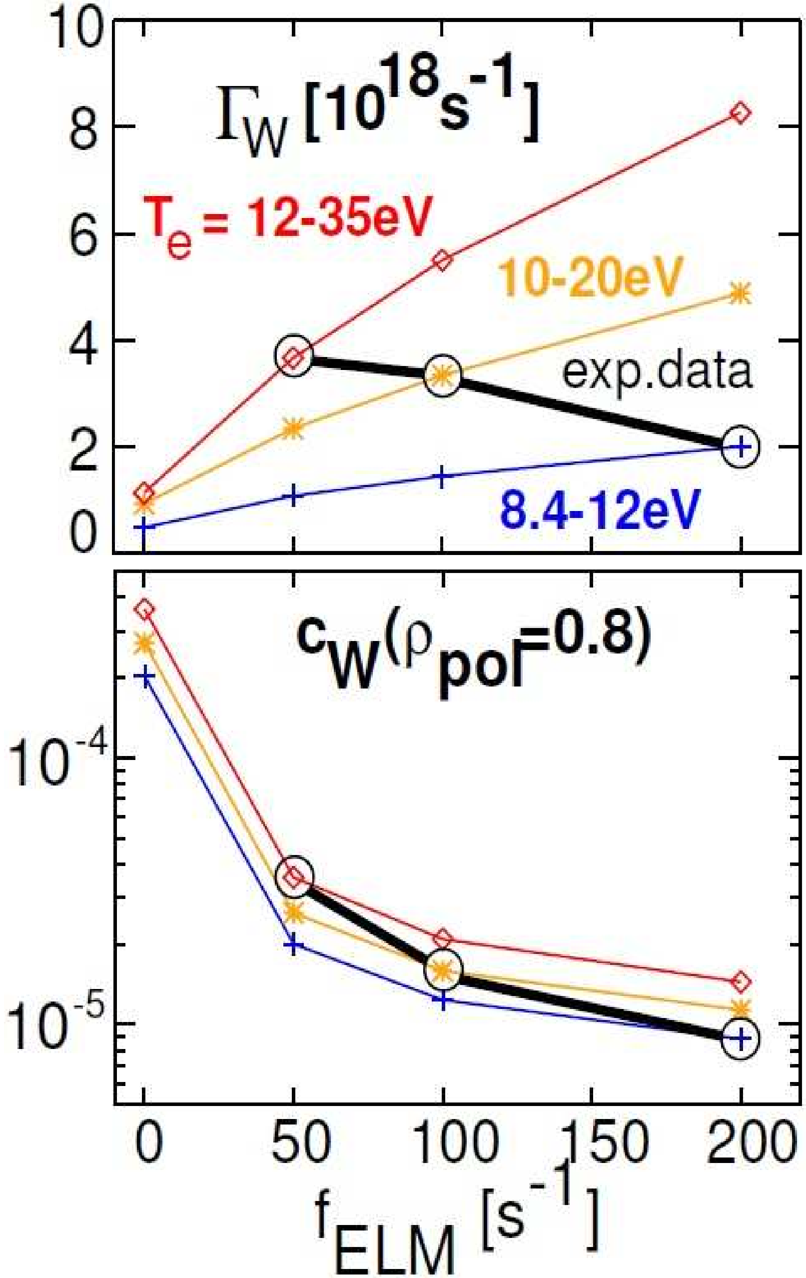
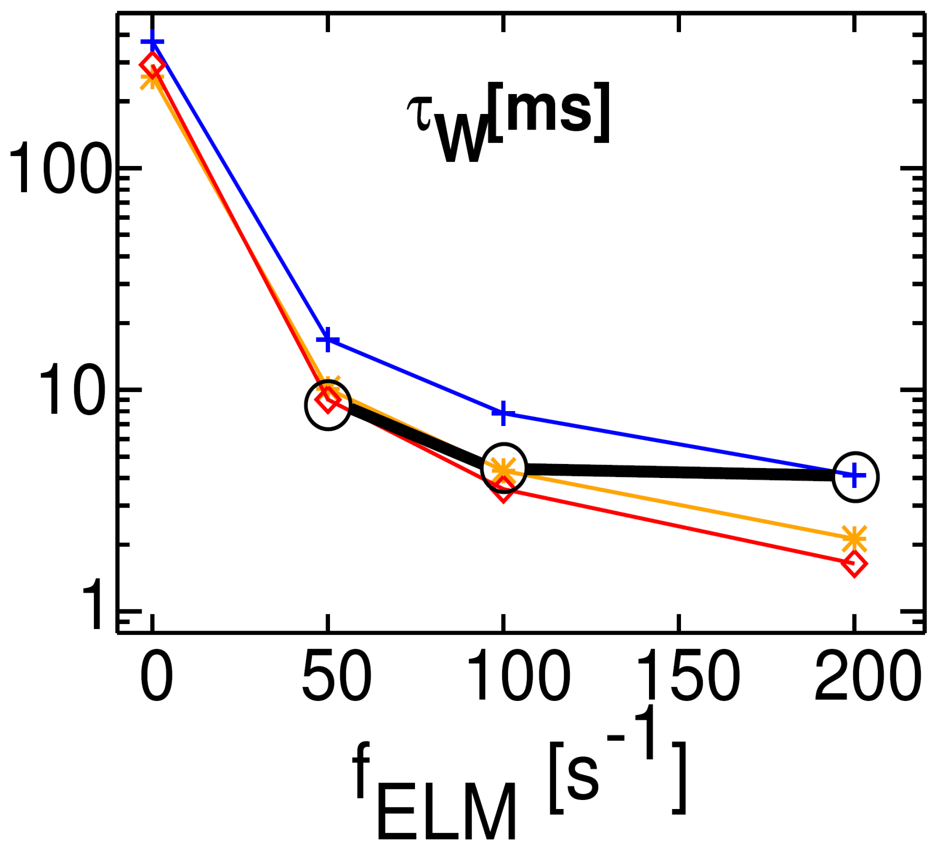
# Feature in Impurity Confinement Time is reproduced by the model




- $\tau_W$ increases for higher puff?
- Is reproduced by the model!
- Hotter SOL leads to more efficient parallel transport



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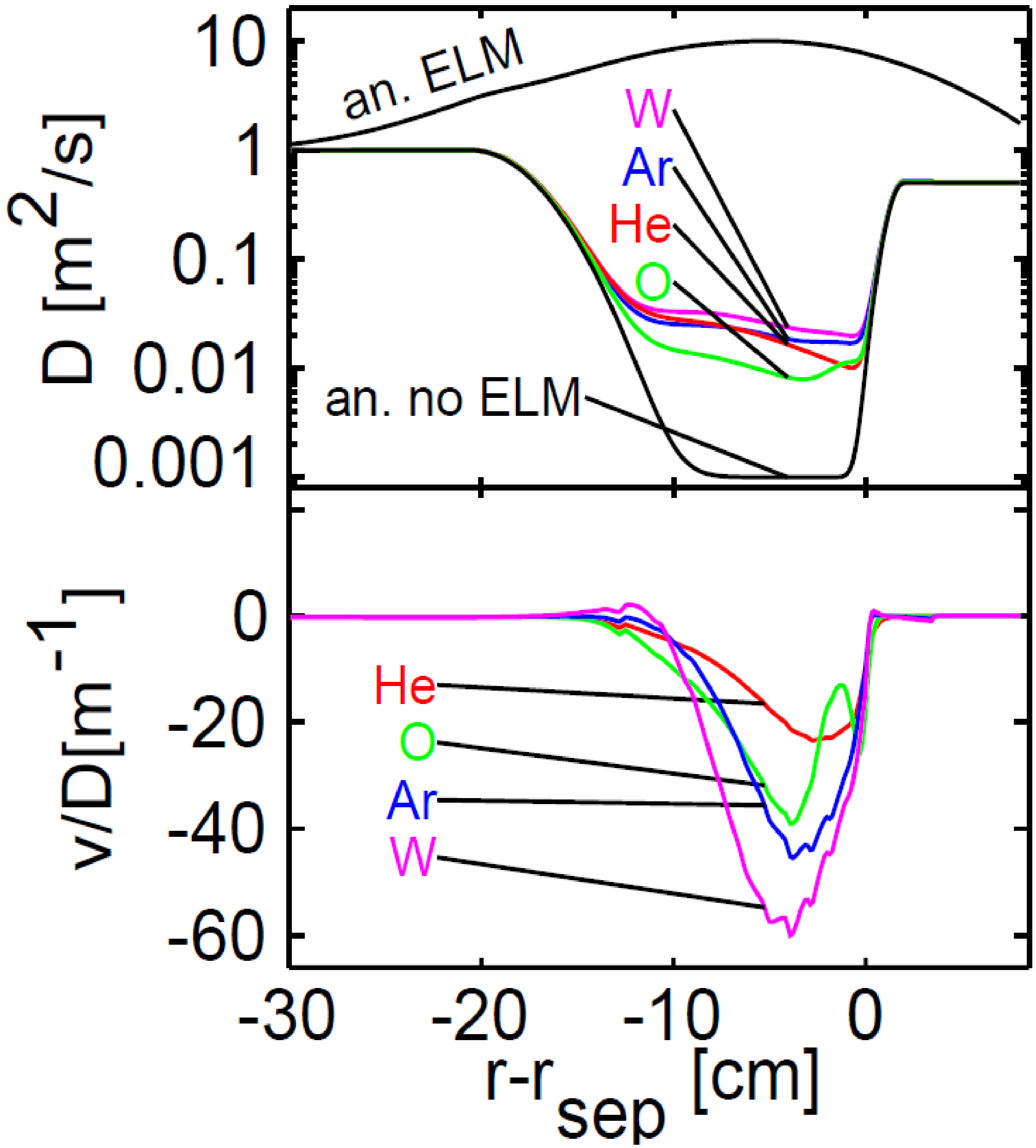
# ETB Transport of Impurities in ITER




- Transport coefficients are smaller than in ASDEX Upgrade (higher T and B)
- Anomalous transport was assumed to still play no role in ETB

$T_{e,ped} = T_{i,ped} = 4.8\text{keV}$

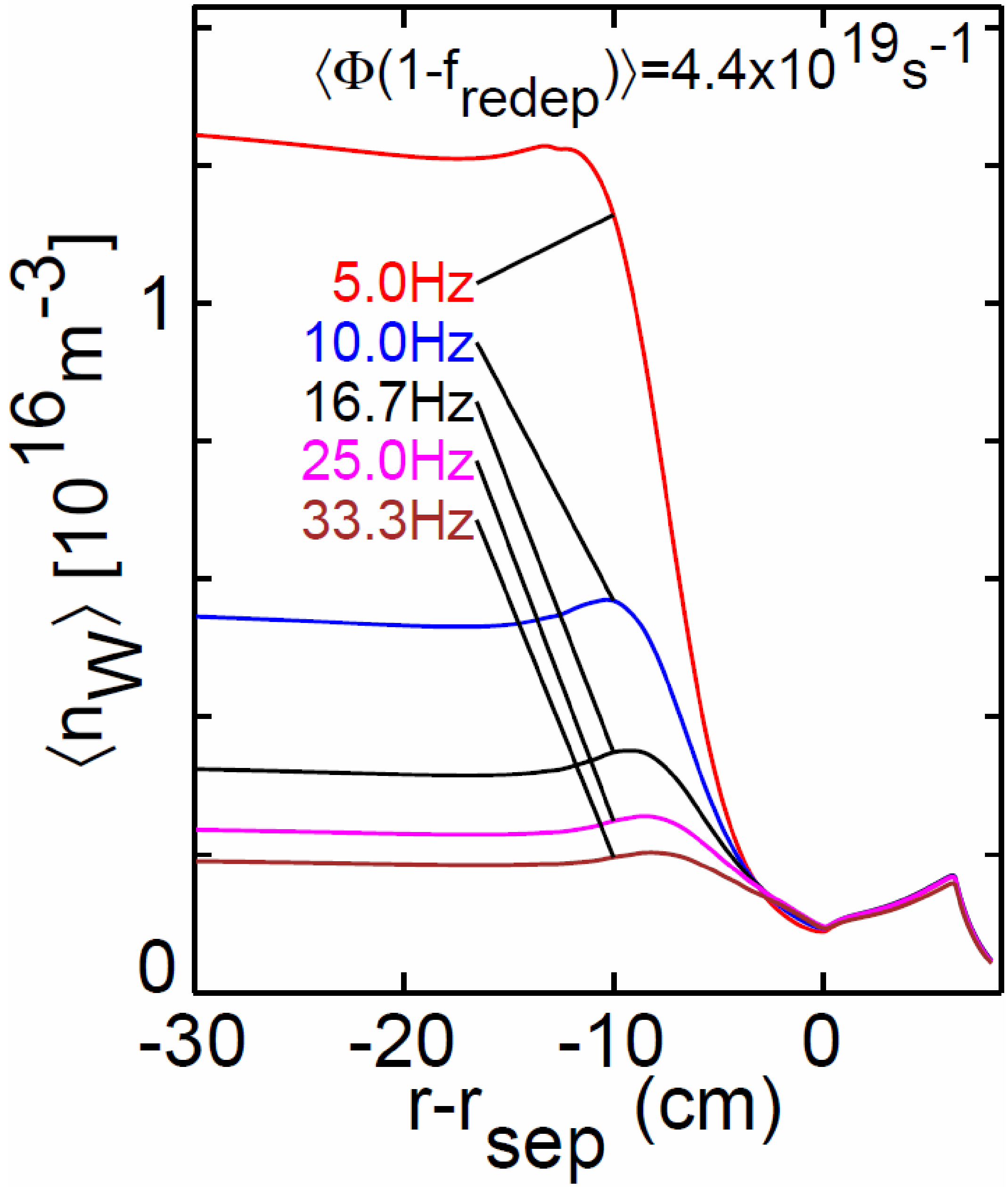
$n_{e,ped} = 7.8 \times 10^{19} m^{-3}$

$B_T = 5.3T$, $I_p = 15MA$

$c_{He} = 2\%$, $c_O = 0.9\%$, $c_{Ar} = 0.05\%$

Dux, R., IAEA 2010

# Prediction: Small Impurity Pedestal in ITER



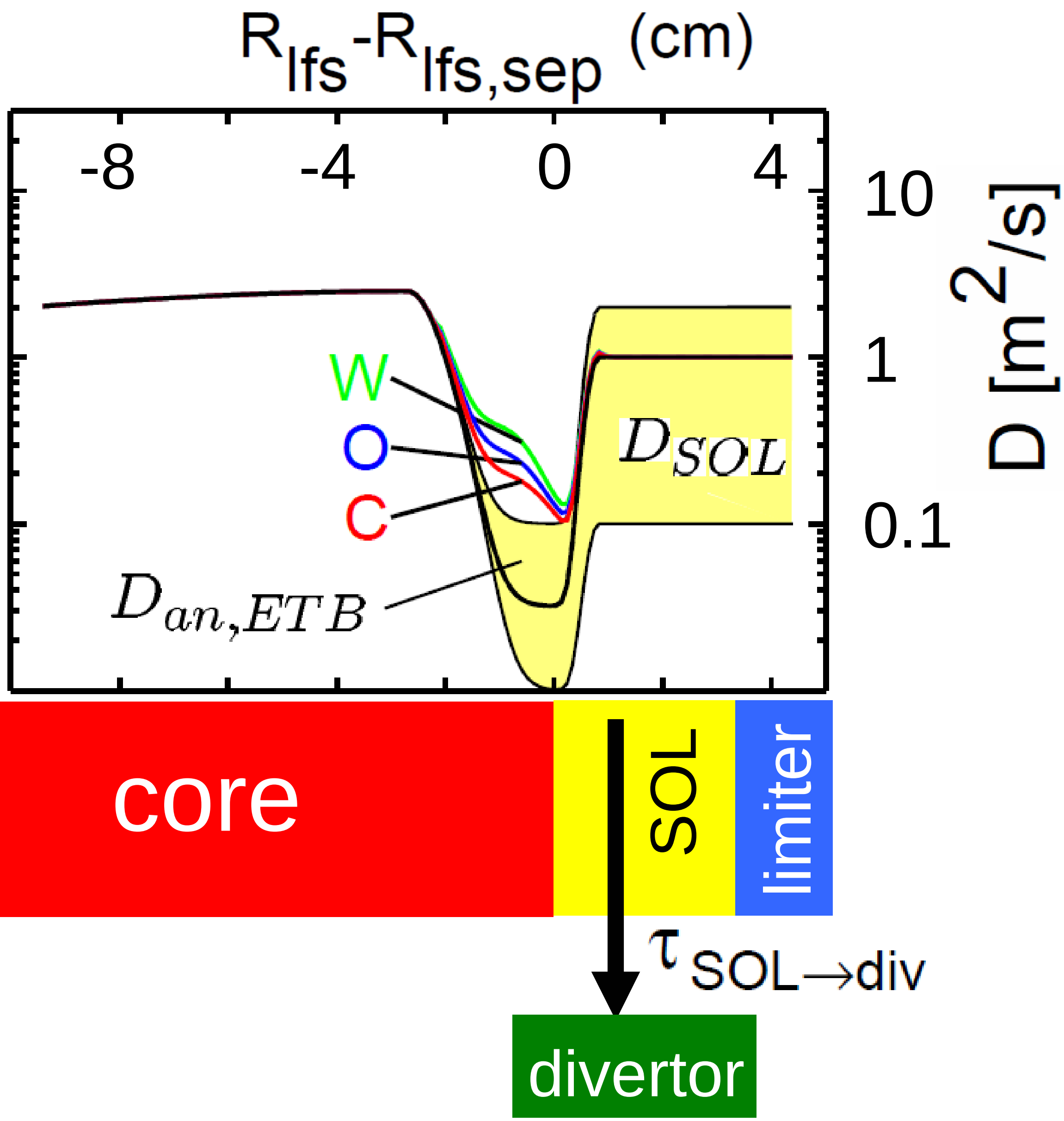

- Pedestal evolves slowly due to small D and v
- Already at 20-30Hz the impurity pedestal is smaller than factor of 3
- ELM frequencies > 30Hz are required from power handling considerations
  - ⇨ No strong impurity pedestal

Dux, R., IAEA 2010

# Summary

- For type-I ELMy H-mode,
  inter-ELM impurity transport at the barrier is neoclassical
  - ⇨ Absolute values of v and D agree
  - ⇨ Neoclassical Z-scaling is observed
- A multi-impurity transport/erosion code was developed combining the transport in the edge barrier and wall erosion including effects of ELMs
  - ⇨ Consistent description including all experimental data
  - ⇨ Model allows to study mechanisms of impurity confinement
- Effect of ELM flushing more important for W concentration than additional impurity source due to ELMs
- Prediction for ITER: Impurity Pedestal will be weak at ELM frequencies above 30Hz

# Perp. Diffusion in SOL is not important

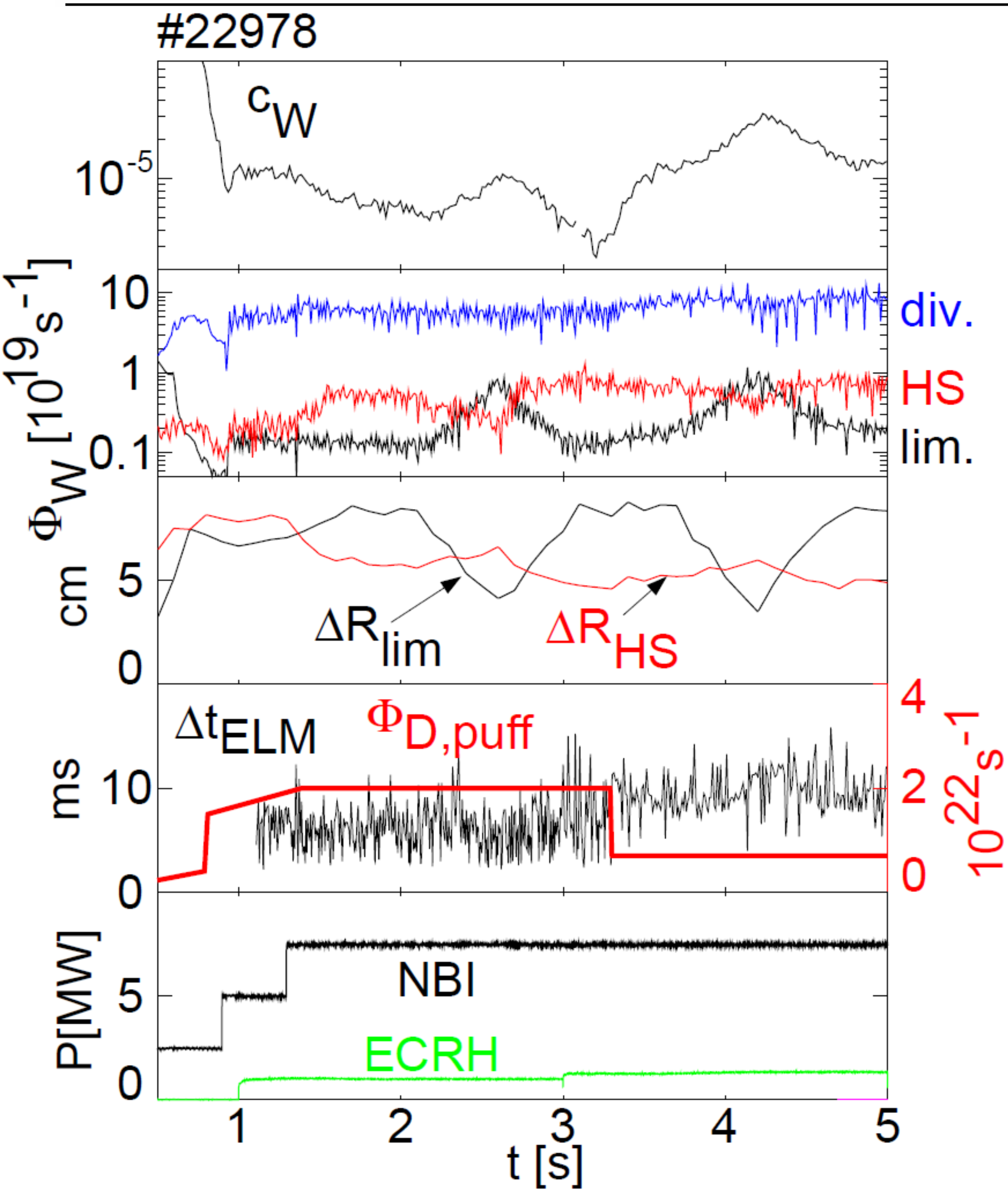




- Investigate the various parameters in the model
- Parameter variation in model yields simple regression formula
- $\tau_p$ in ms =

$$14\ f_{ELM}^{-1.1} \langle\tau_{SOL\rightarrow div}\rangle^{1.1}\ D_{SOL}^{0.1}$$

Dux, R., IAEA 2010

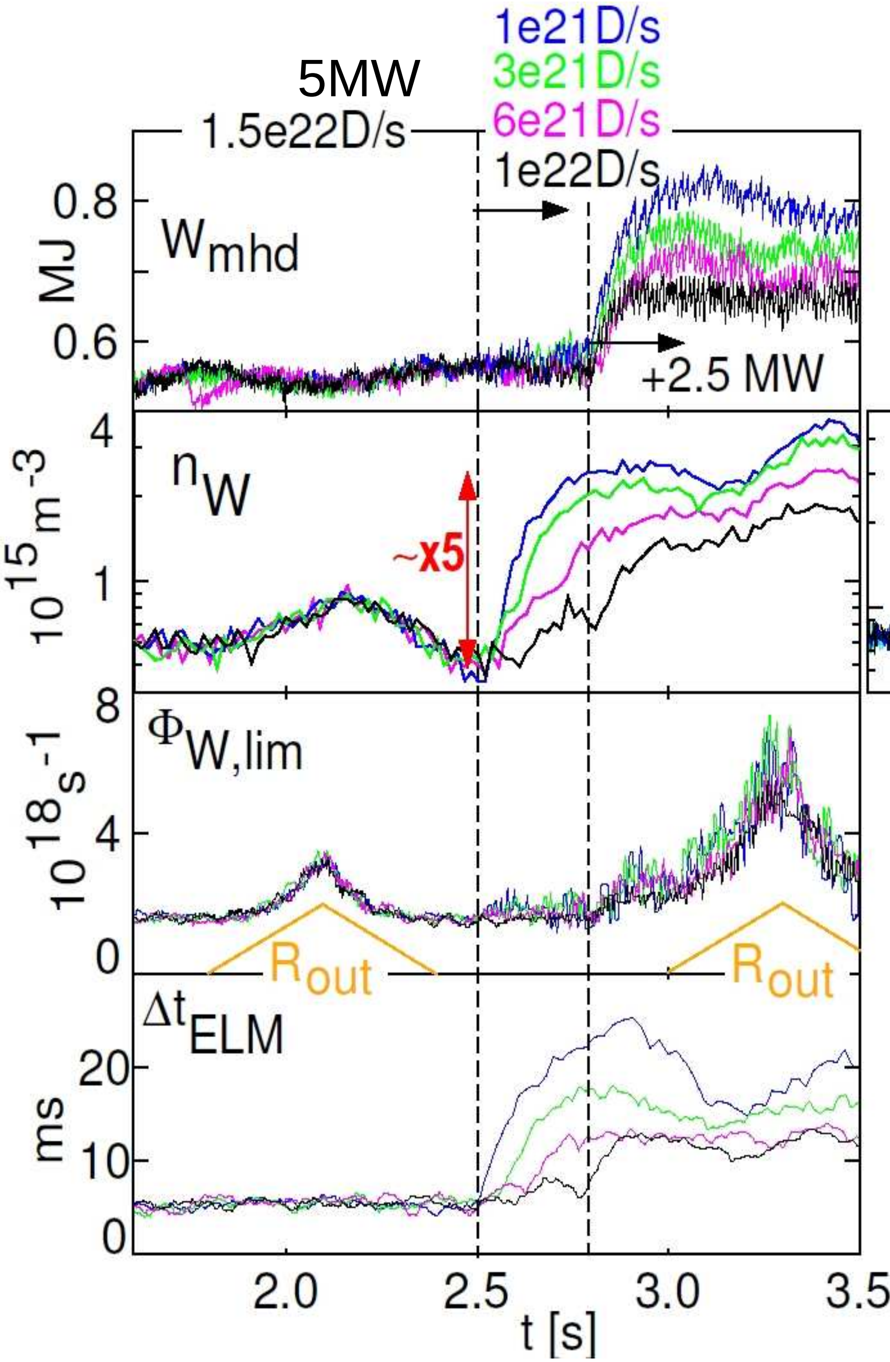
# Outboard limiters most important source

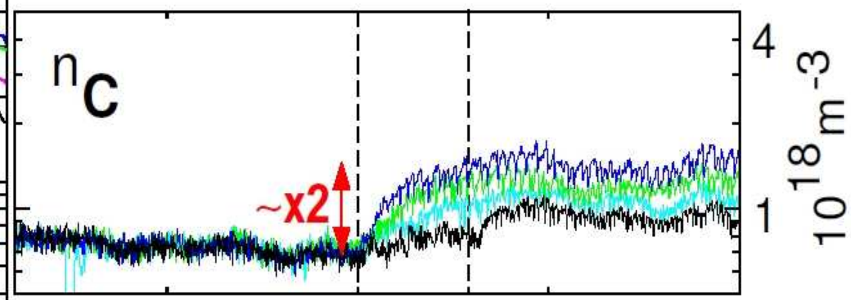



- R-sweep modulates outboard W-source
- Large divertor source does not play a role
- $c_W$ reacts strongly to the limiter source

R. Dux et. al., I-6 , PSI 2008, JNM **390-391**, 858

# W- and C-density pedestal vs. ELM frequ.



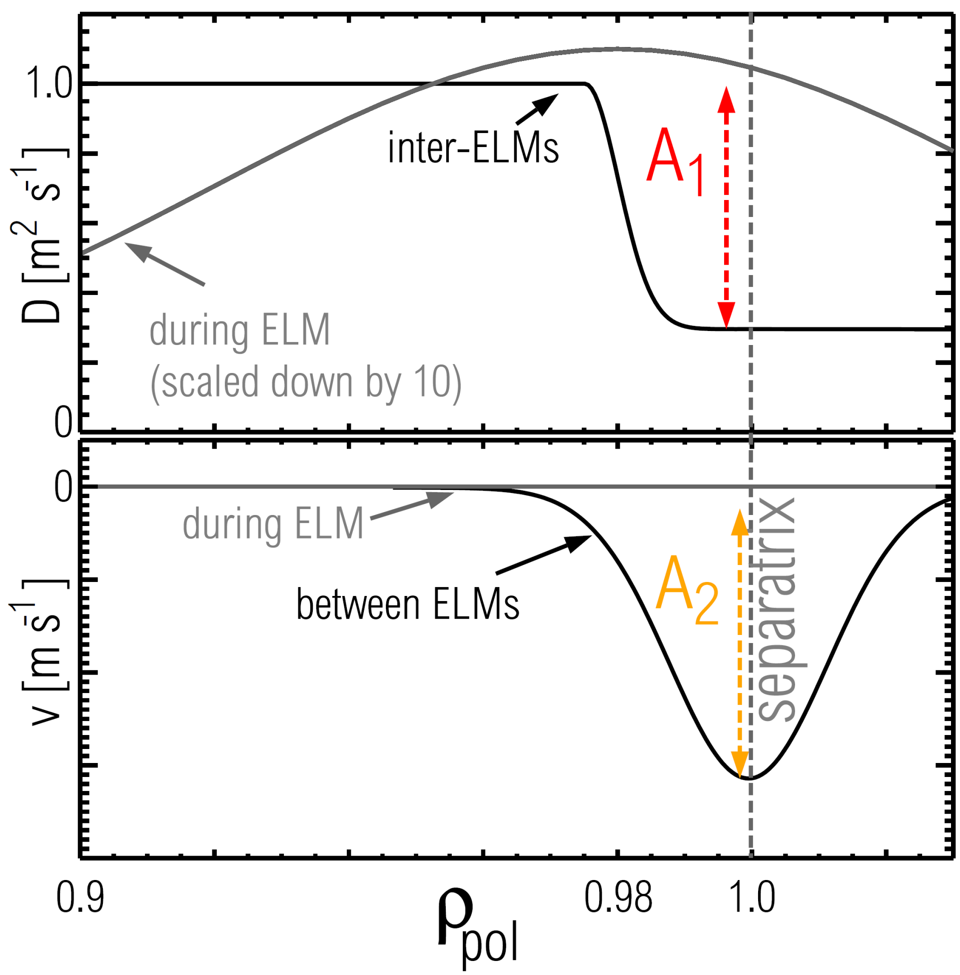




- Scan in D-puff rate changes ELM frequency
- Lower ELM frequency leads to more $n_W$ inside pedestal

- Most important source outboard protection limiters
- $n_C$ increases less strong with $\Delta t_{ELM}$ than $n_W$

# Scheme of Transport Measurement

Fitting procedure




Vary

$A_1$,$A_2$

Electron profiles, Geometry, Atomic Data

input

1D-Transport Model

STRAHL

compare

Measured impurity profiles