The Tungsten Programme in ASDEX Upgrade

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- Rationales for materials selection
- Transition to W PFCs in ASDEX Upgrade
- Start-up of un-boronised machine
- W sources and W content
- Conclusion / Outlook

Rationales for materials selection

Low erosion rates:

→ low power loss by dilution / radiation originating from impurities

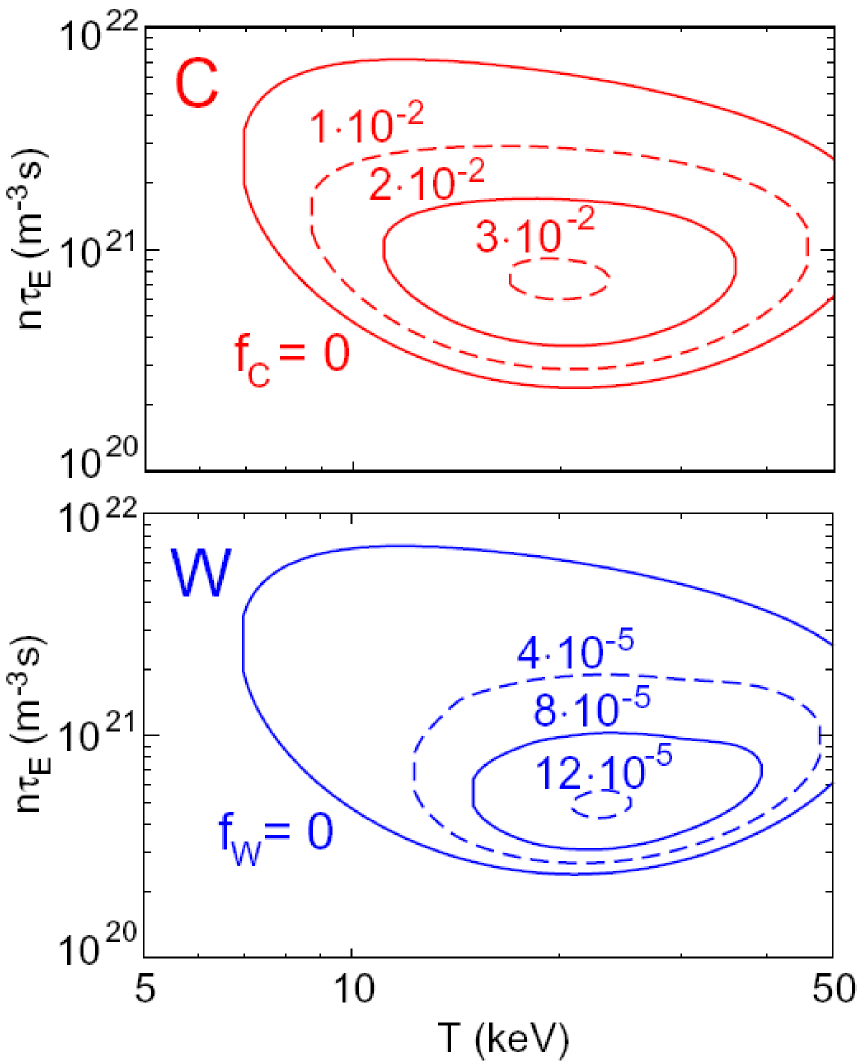
→ long lifetime of PFCs

→ low dust production

→ low T co-deposition

Low atomic number

→ low radiation loss parameter



Losses through

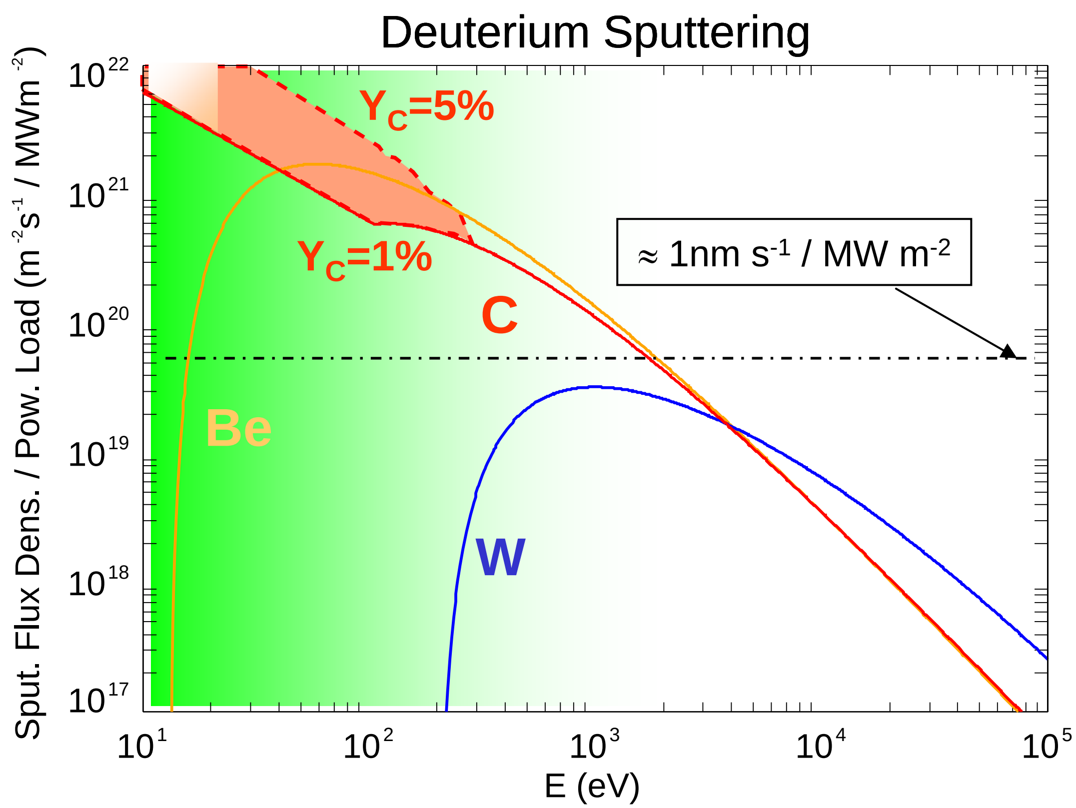
dilution (low-Z) : $n_{DT} = n_e(1 - Zn_Z)$

radiation (high-Z) : $P_{rad} / V = L_Z\, n_Z\, n_e$

Rationals for material selection

sputter-flux / power load

- strong decrease with higher particle energies at similar power loads
- high-Z best for D-energies < 300 eV
- low-Z better at high D-energies



fluences in a reactor will be much higher
⇒ use of low-Z armour may not be possible!

Steps in ASDEX Upgrade towards a full W device

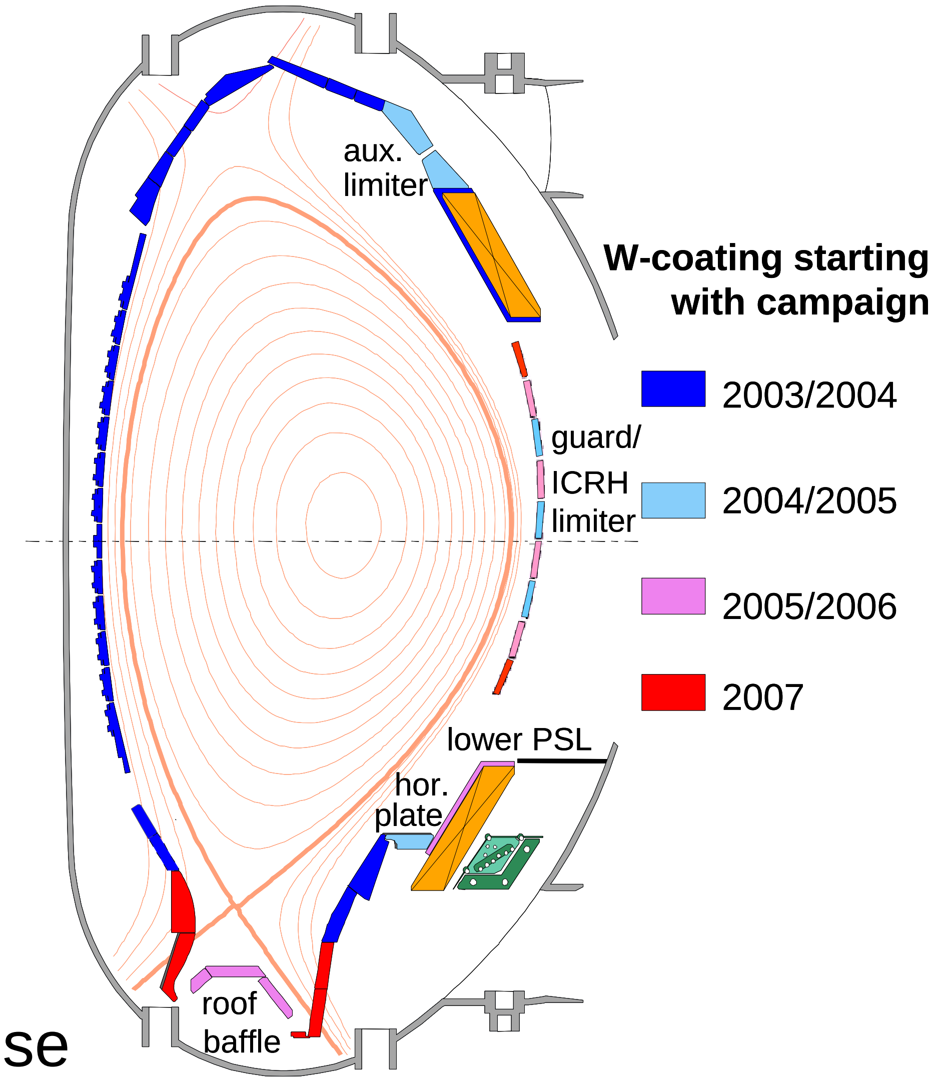
Steady increase of area
of main chamber W PFCs
since 1999

Rationales:

- risk minimisation
- physics investigations
- partitioning of installation time
- production capacity

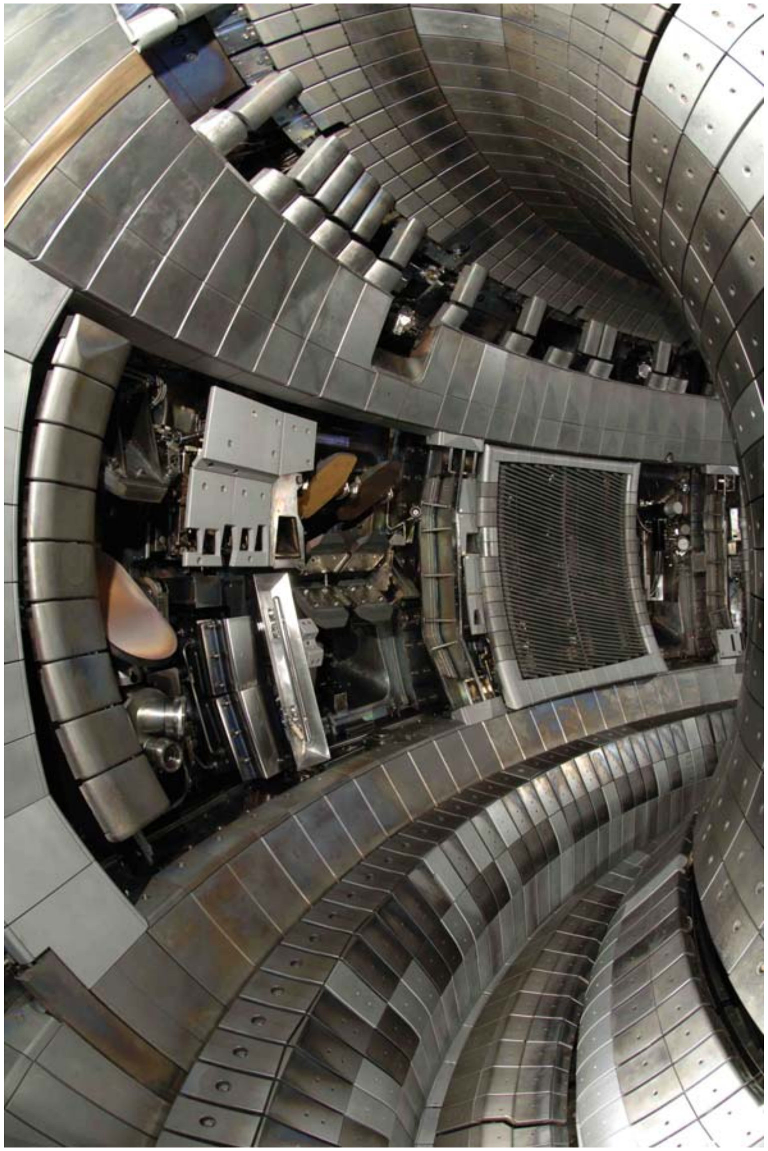
W coating on graphite:

- 200 µm W VPS at outer SP
- 3-5 µm W PVD everywhere else



Steps in ASDEX Upgrade towards a full W device

IPP



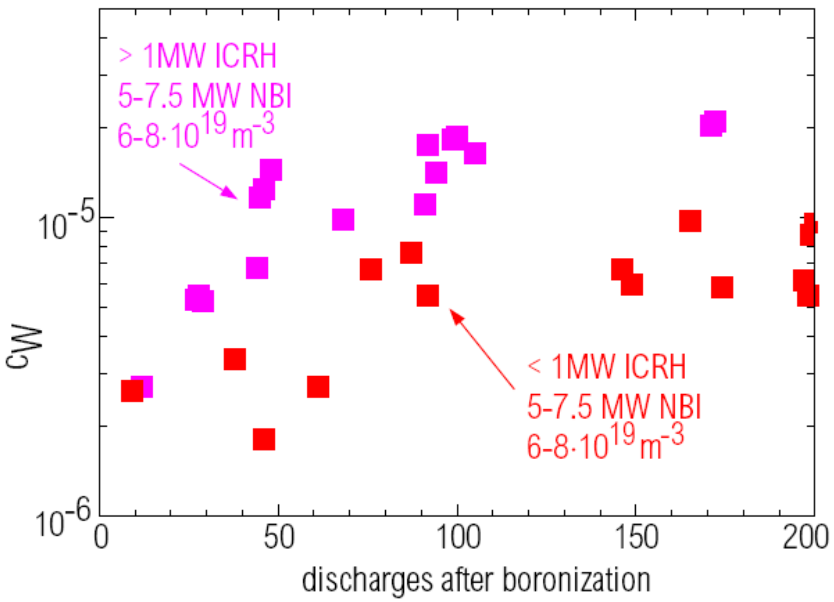
Effects of Boronisation

- Conditioning
  - large O getter (even at non plasma exposed areas):
  - ⇒ easier break down
  - ⇒ higher density limit
  - ⇒ facilitates start up

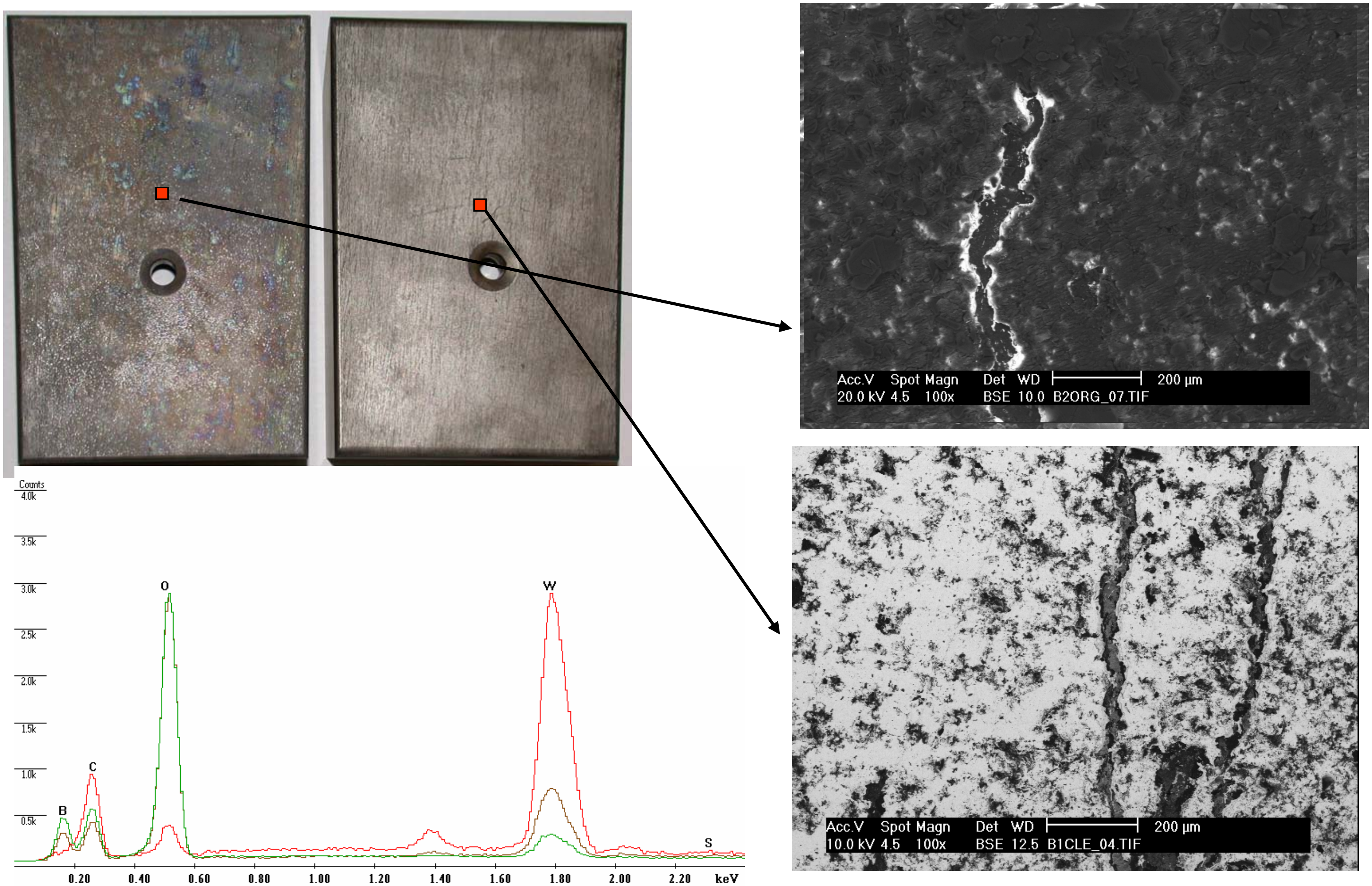
however:
may be difficult to be performed in staedy state devices

- Coating of surfaces
  - suppression of W influx
  - suppression of other intrinsic metallic impurities

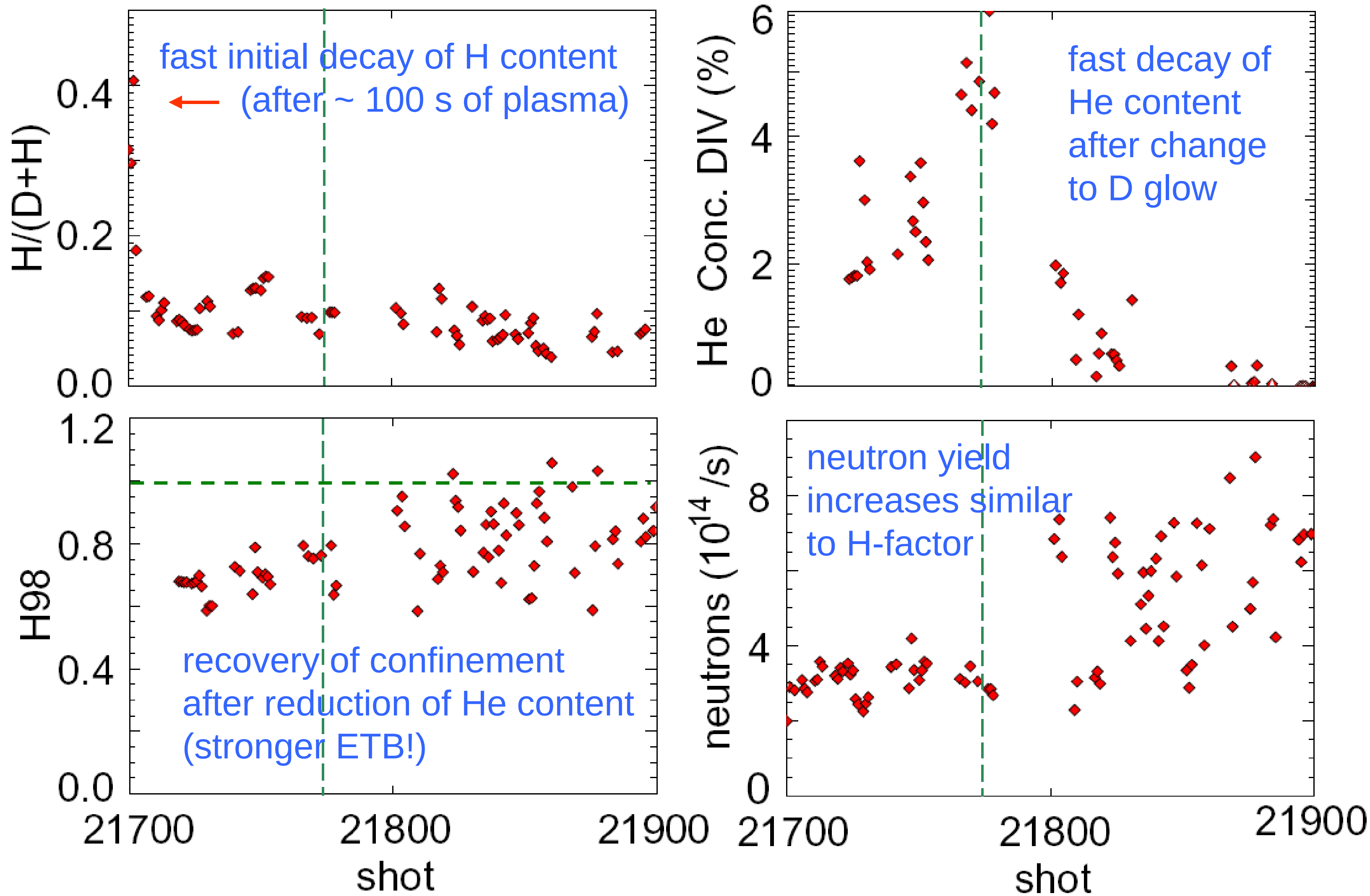
⇒ facilitates operation



Removal of surface layers by mechanical cleaning



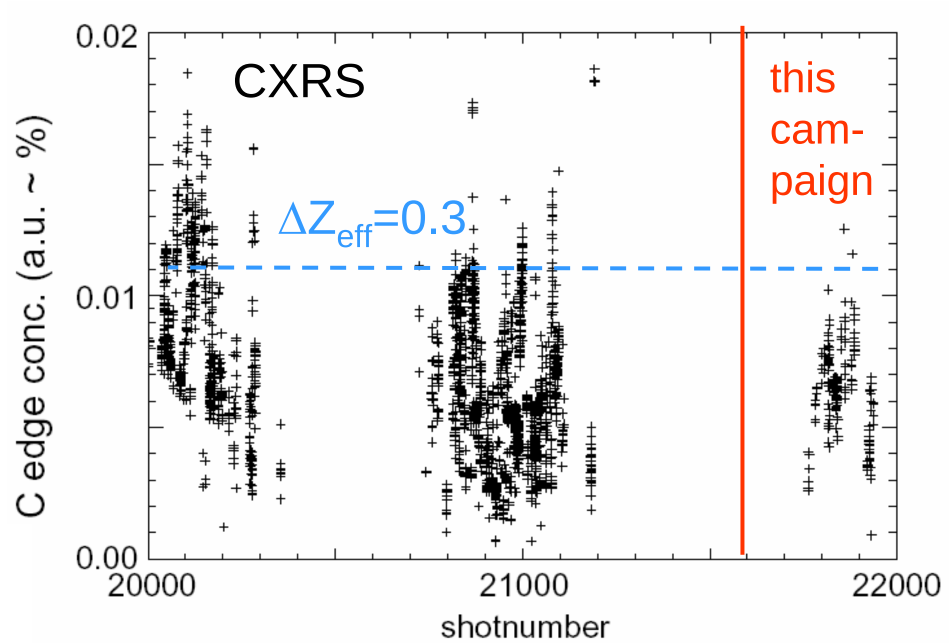
Development of H-mode discharges @ 0.8 MA, 7.5 MW

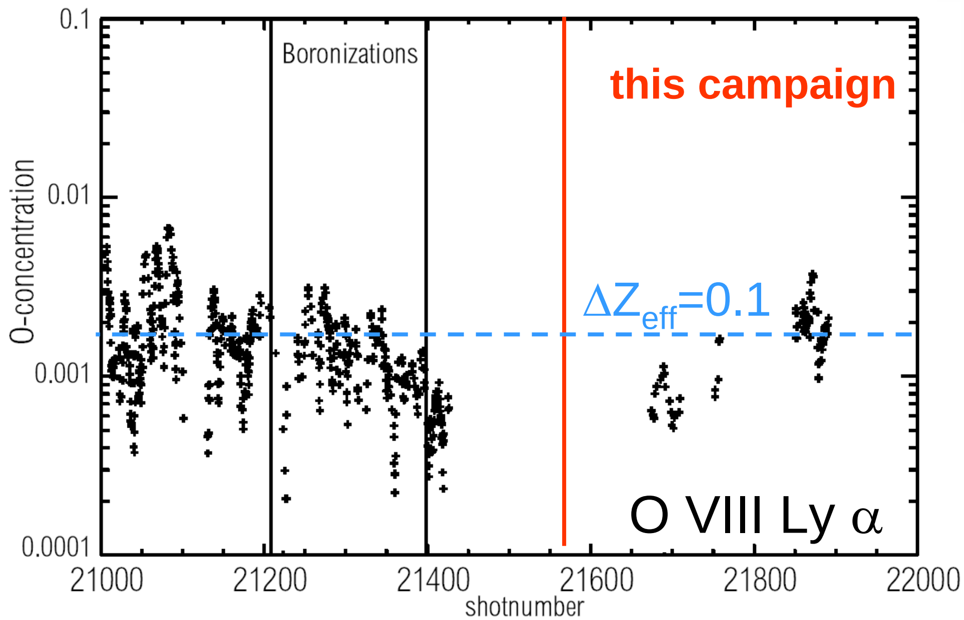


He retention and release much higher in W compared to C (K. Schmid, IAEA 2006)

Evolution of low Z content

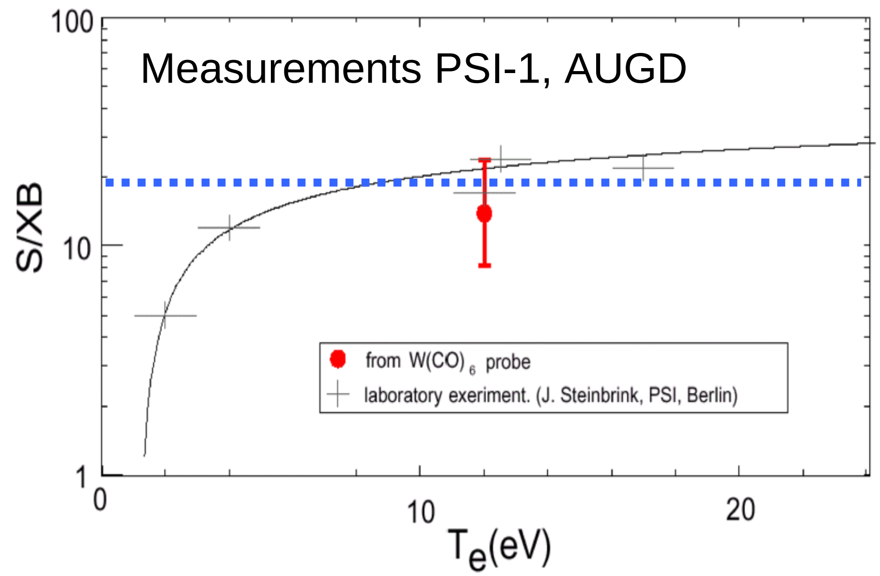
C similar as in last campaign (≤ 1%), strongly depending on discharge conditions, up to now only slow decrease !

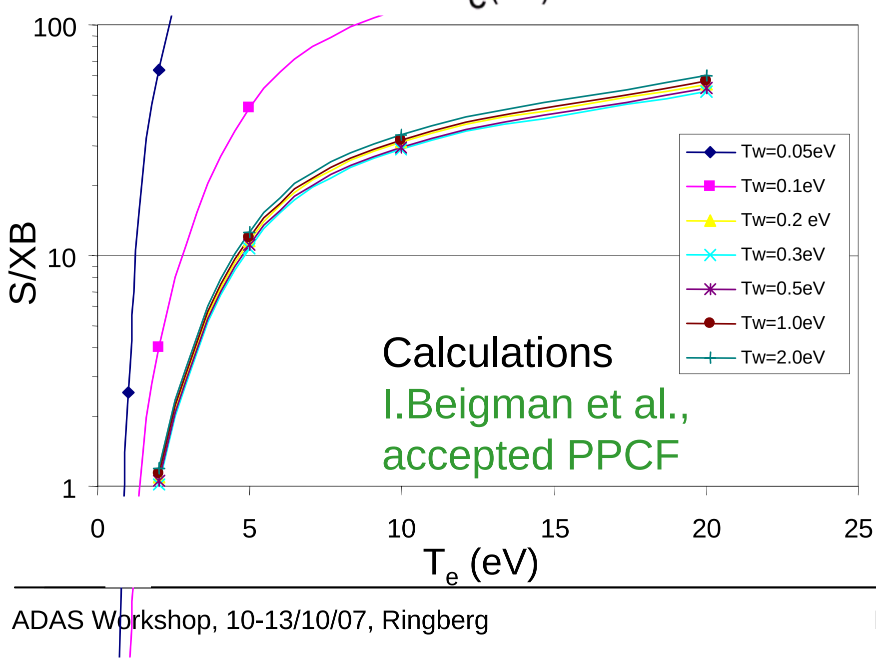




O concentrations similar to previous campaigns (however no significant reduction during campaign)

Visible W-spectroscopy for influx measurements





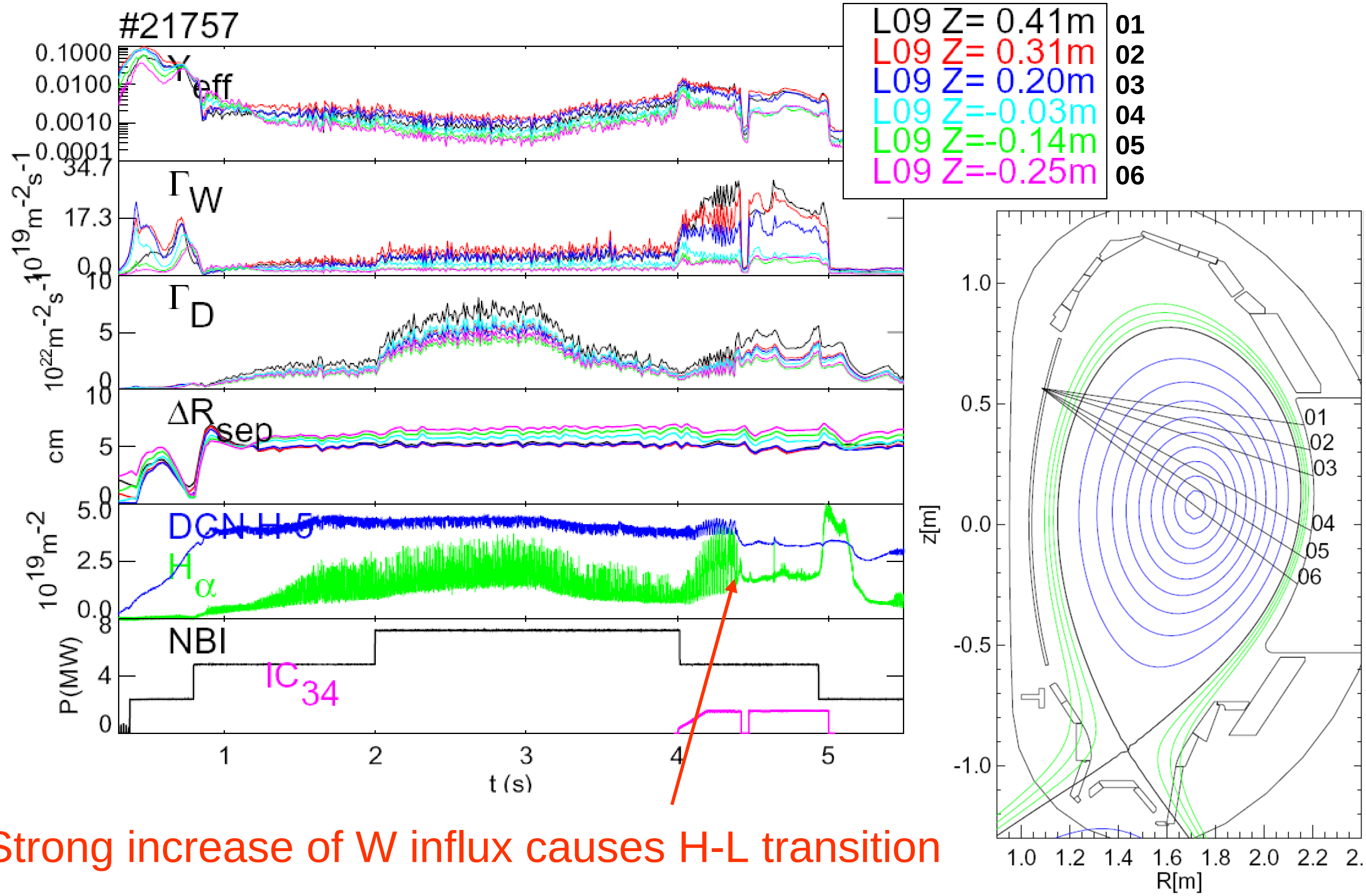
W I @ 400.9 nm
S/XB=20 (const.) used for calculation of W influx

Calculations (I. Beigmann et al.) agree reasonably well with experiment

Other lines proposed for influx measurements (in more suitable wavelength ranges)

S/XB for WII lines highly desirable for measurement of net W influx

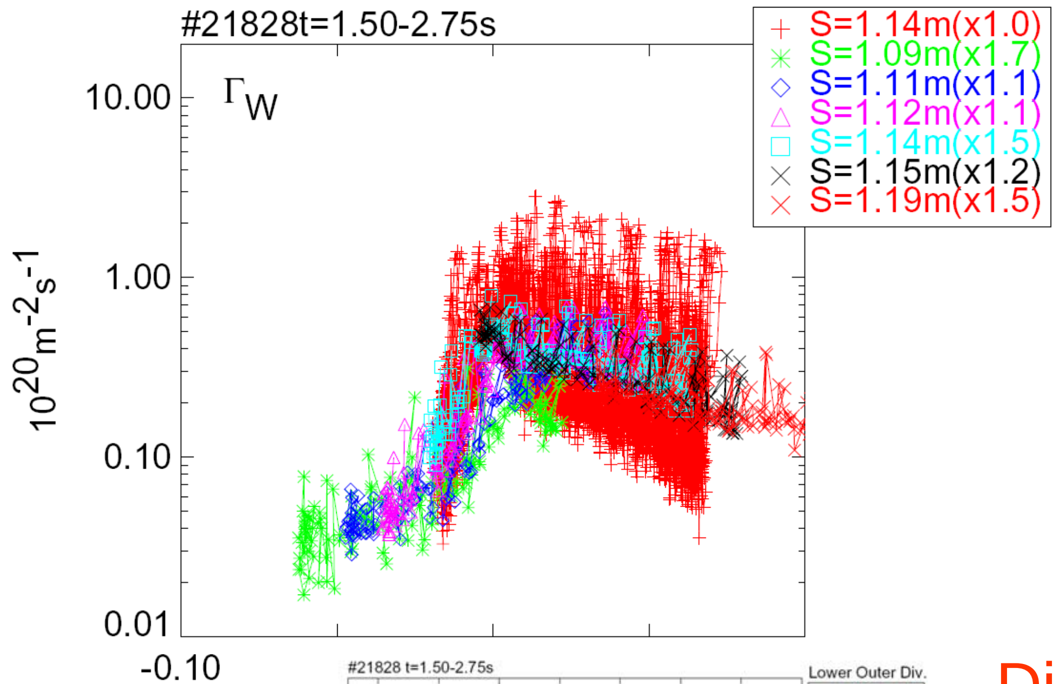
W sputtering at ICRH antenna limiters: largest W erosion at upper limiter end

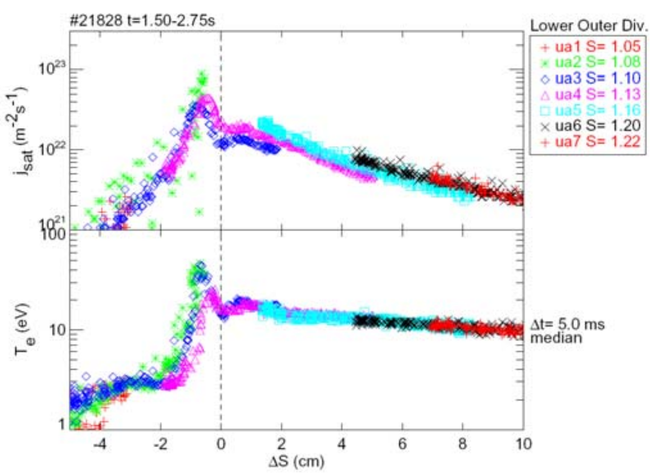


Strong increase of W influx causes H-L transition

Similar behaviour at open and closed Faraday screens

W erosion in the divertor





Strikepoint scans:

- Γ_W peaked at separatrix
- ELMs can by resolved with fast camera
- erosion profile resembles profiles of T_e and j_{sat}

Divertor is largest W gross source (~10^{20}/s), but main chamber fluxes (few 10^{19}/s) dominate W content

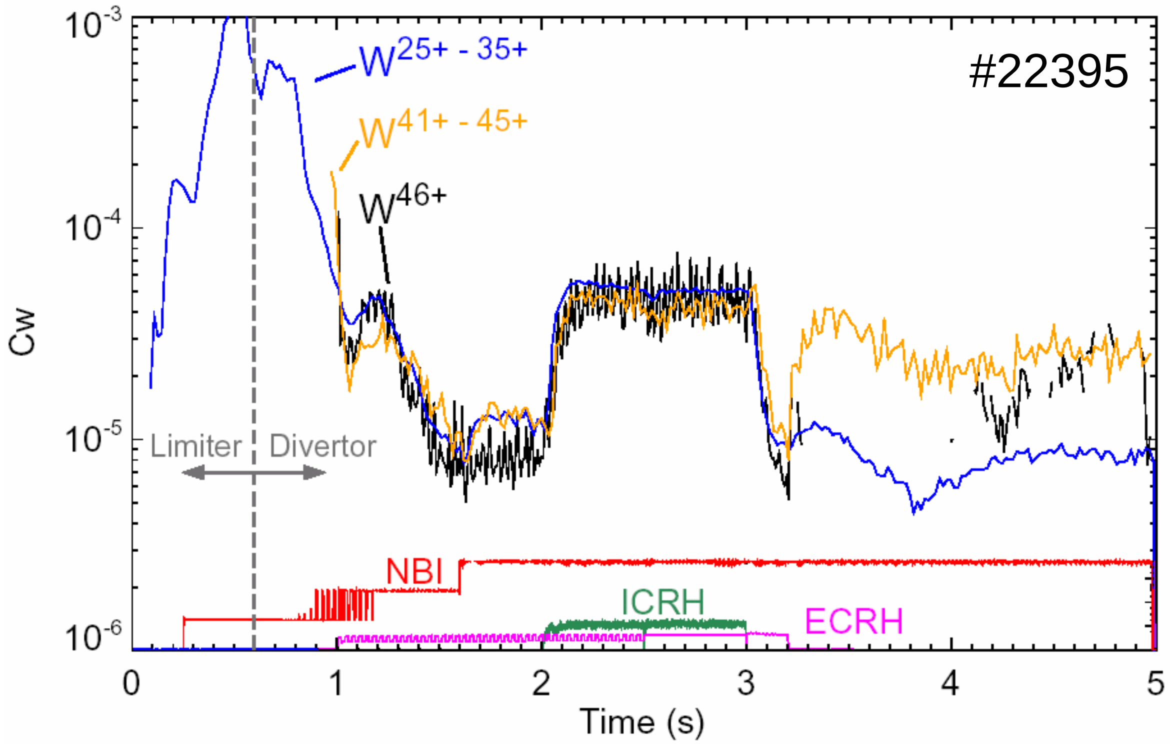
Details on W influxes:
R. Dux, this workshop

VUV and SXR spectroscopy for W density measurements

- typically, ion states up to W^{48+} exist in AUG plasmas
- spectral lines from different ion states used for extraction of concentration

⇒ several points for radial concentration profile

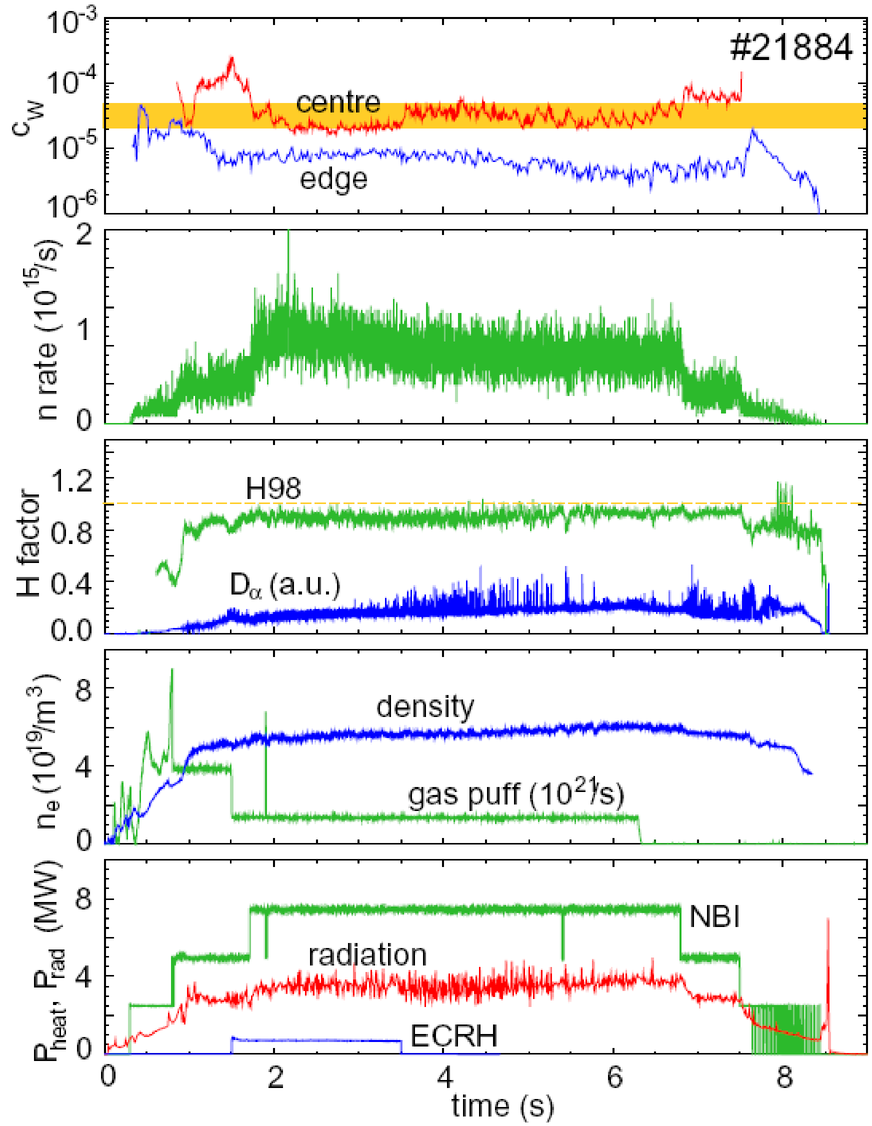
W-concentration during phases with different auxiliary heating



High confinement with moderate W concentrations

Results with unboronized full W device

- confinement close to H~1.0
- central c_W around allowed ITER value
- small amounts of central ECRH reduce W peaking
- radiation typically 60% at intermediate density



Conclusion / Outlook

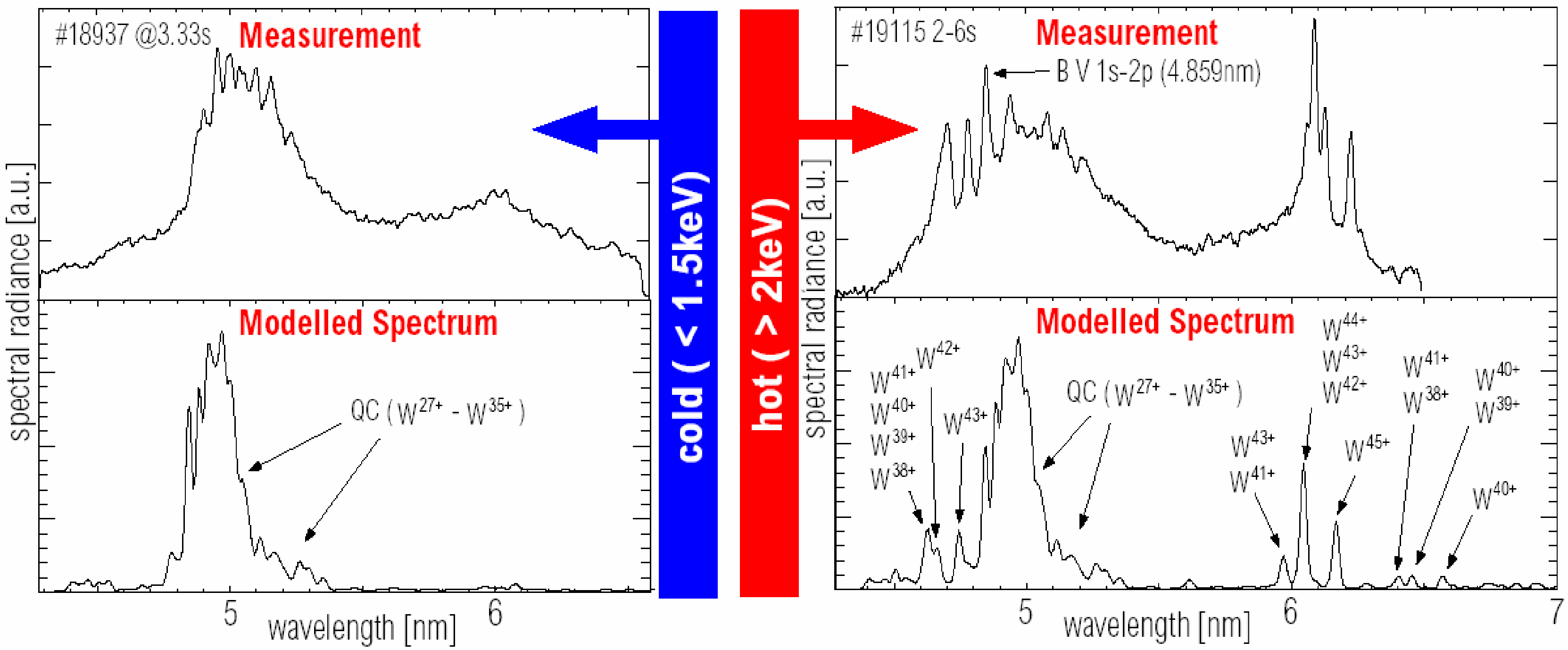
- 100% W PFCs completed
- successful start-up of AUG without prior boronisation
- milestone (H=1) quickly reached after reduction of He content
- low low-Z contamination (C<1%, O<0.5%, …), but no strong reduction of C influxes observed yet (microscopic sources?)
- comprehensive spectroscopic W diagnostic (influx, density) allows detailed investigations on sources and penetration
- erosion by fast / non thermal particle important
- W concentrations similar to ones with old boronisation in the previous campaign (< few 10^{-5}), mostly governed by transport (except during ICRH)

- Extension of working space (improved H-Mode) / W diagnostic

W Spectroscopy in the VUV and SXR
Detailed investigations in the VUV

- Around 5 nm: Features emitted at $T_e \approx 0.8 - 1.5$ keV and at $1.8 - 4.5$ keV
- Detailed EBIT measurements (Berlin, LLNL) available
- Disagreement in many details
- Rough structure of predictions is found in the spectrum

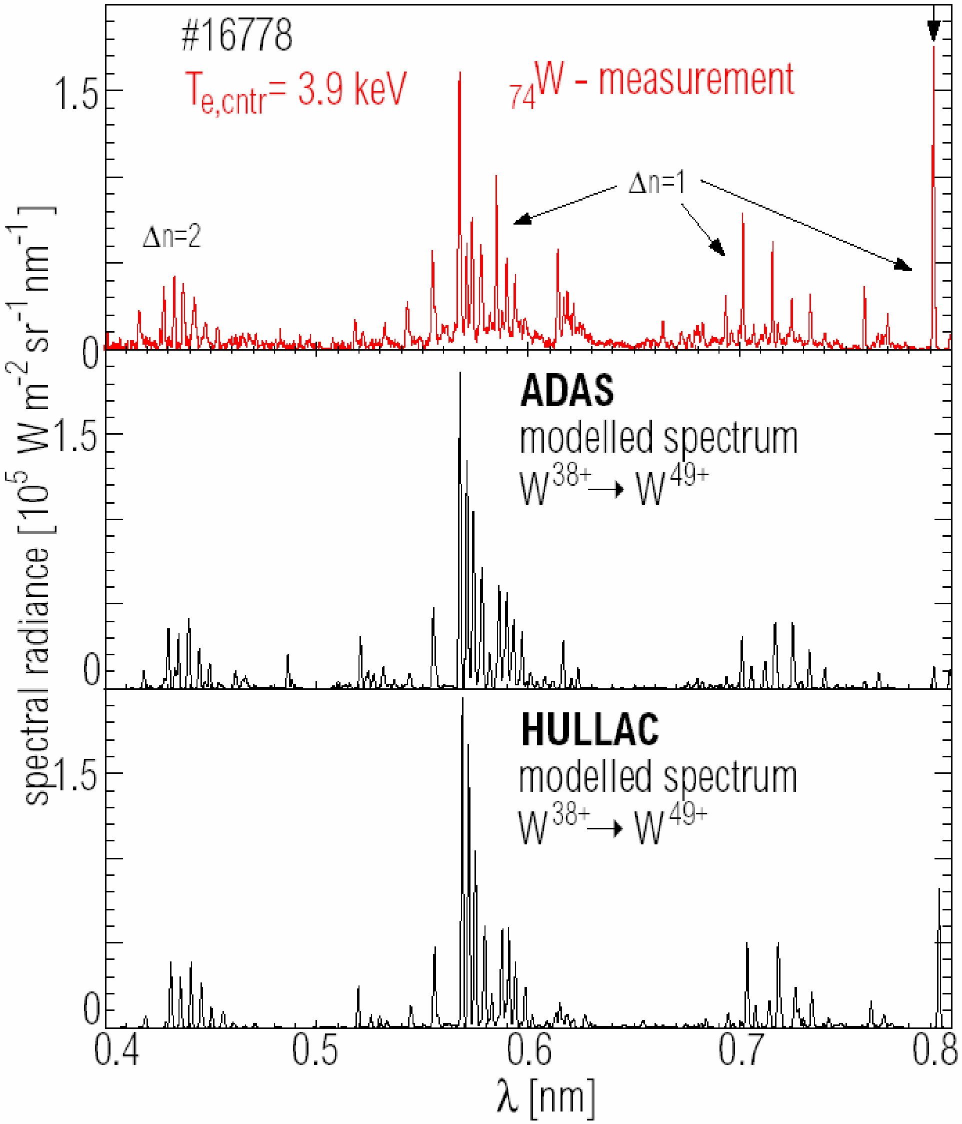
Th. Pütterich (JPB 2005)



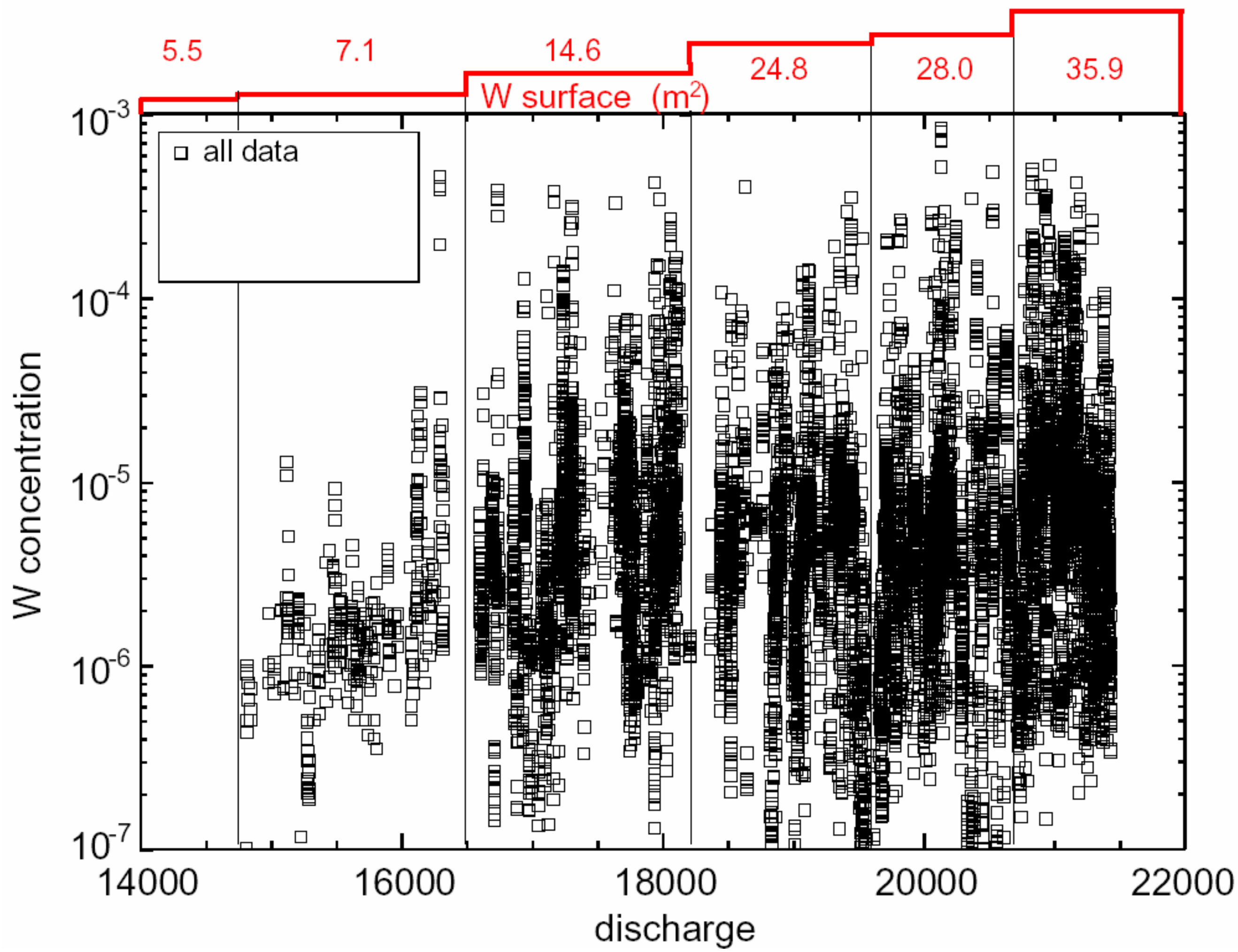
W Spectroscopy in the VUV and SXR
Detailed investigations in SXR region

- Spectral lines of Kr-like W^{38+} to about Mn-like W^{49+}
- Ni-like W^{46+} exhibits most intense spectral lines
- At ASDEX Upgrade the electric quadrupole line at 0.793 nm is monitored

Th. Pütterich (PhD thesis)

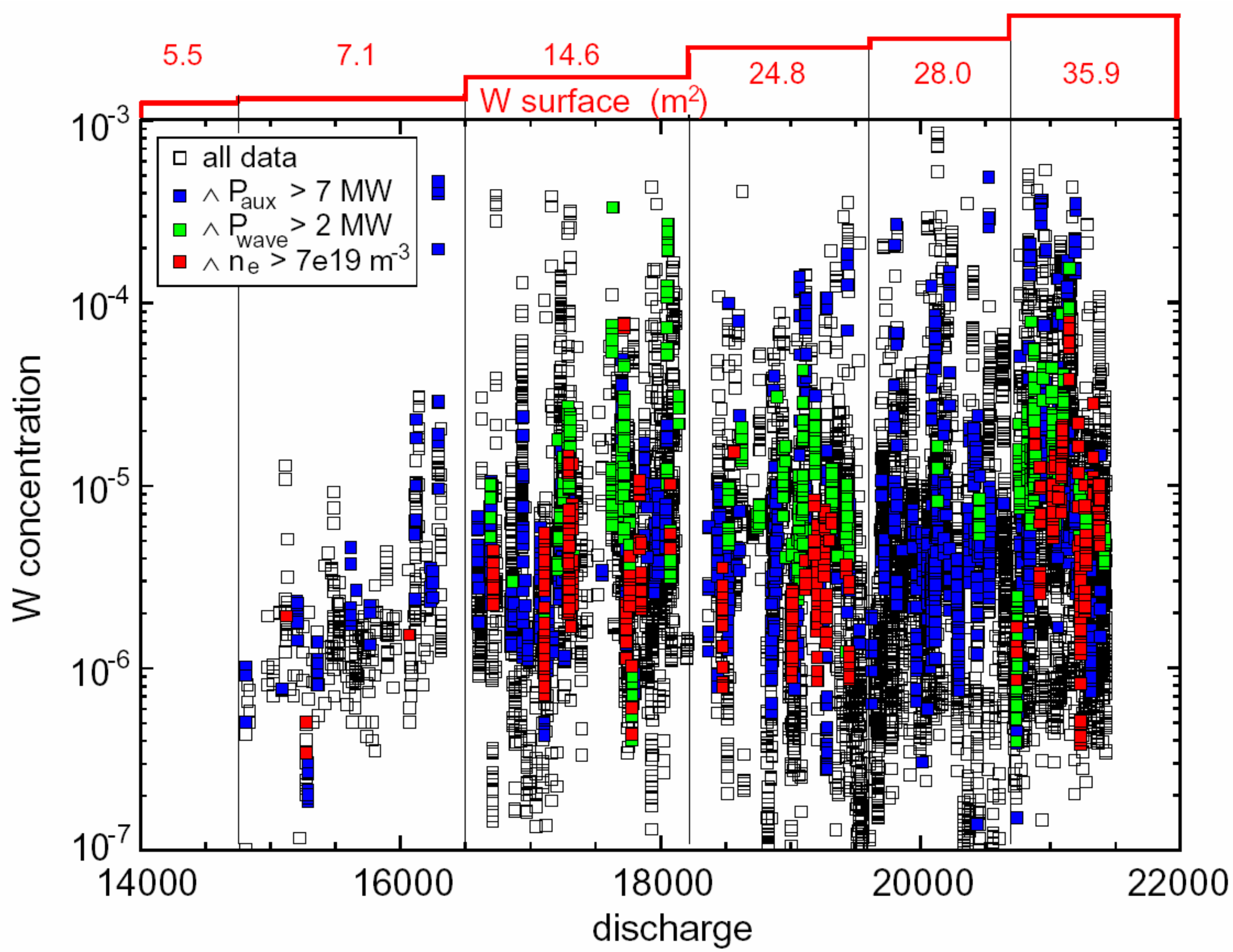


Long term evolution of W concentrations



increase with W coverage, saturation of mean value around 10^{-5}

Long term evolution of W concentrations



- reduced c_W at relevant auxiliary heating power and densities