ASDEX Upgrade

Max-Planck-Institut
für Plasmaphysik

W Influx Measurements in ASDEX Upgrade

R. Dux,
T.Pütterich, A. Janzer, and ASDEX Upgrade Team

Introduction

- experimental setup for spectroscopic
  W influx measurements

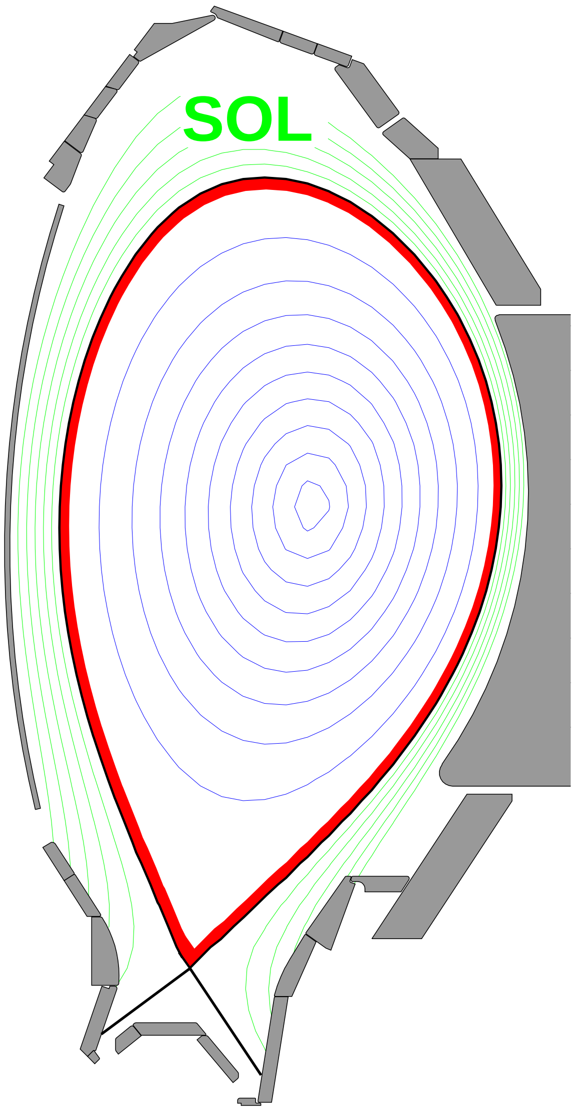
- comparison with erosion measurements

- evolution of W influx profiles during H-Mode discharges
  - effect of ELMs
  - effect ICRF heating

- yield for physical sputtering of W

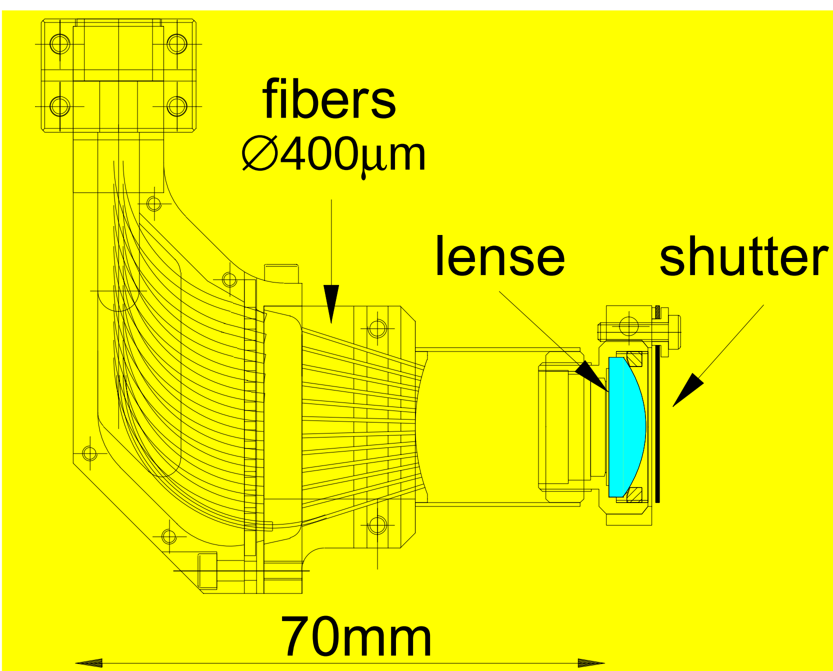
- influence of W influx from different regions on W content in confined plasma

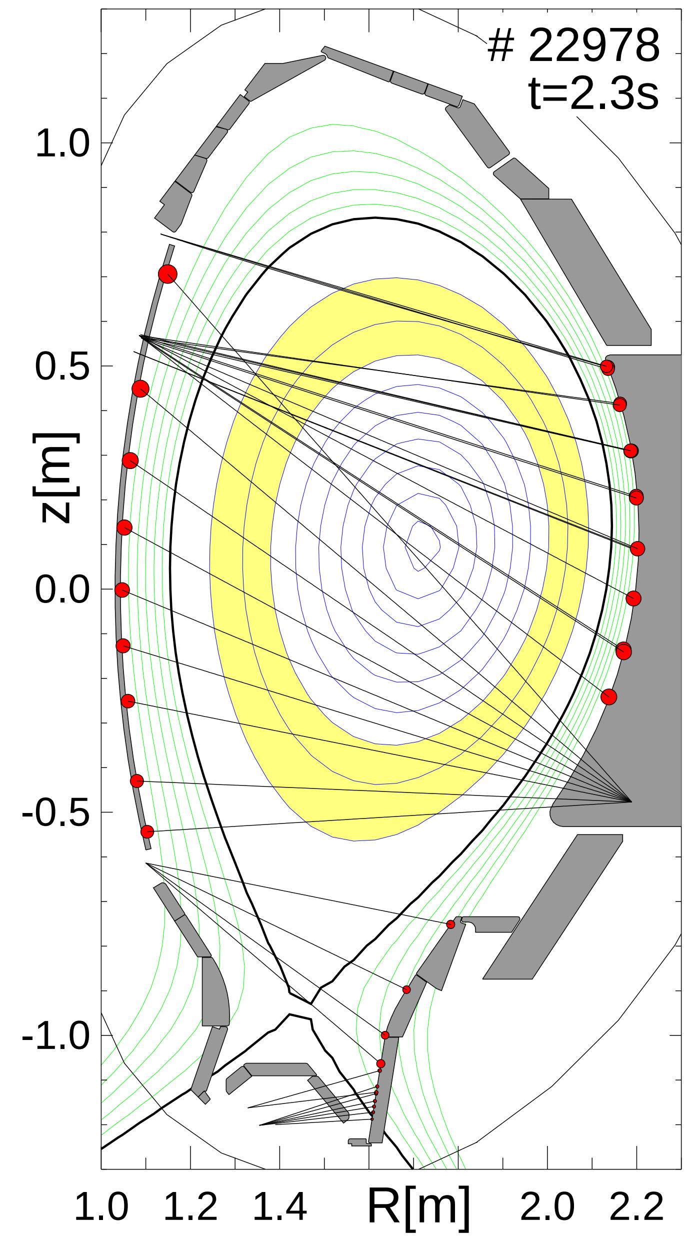
ASDEX Upgrade with W
Plasma Facing Components



Spectroscopic setup for W influx measurements

- small optical heads in shadowed areas
- silica fibers (∅400μm,~25dB/km at 400nm)
- spectrometer(180mm, f#=2.8) + back-illum. CCD
- WI (400.8nm)

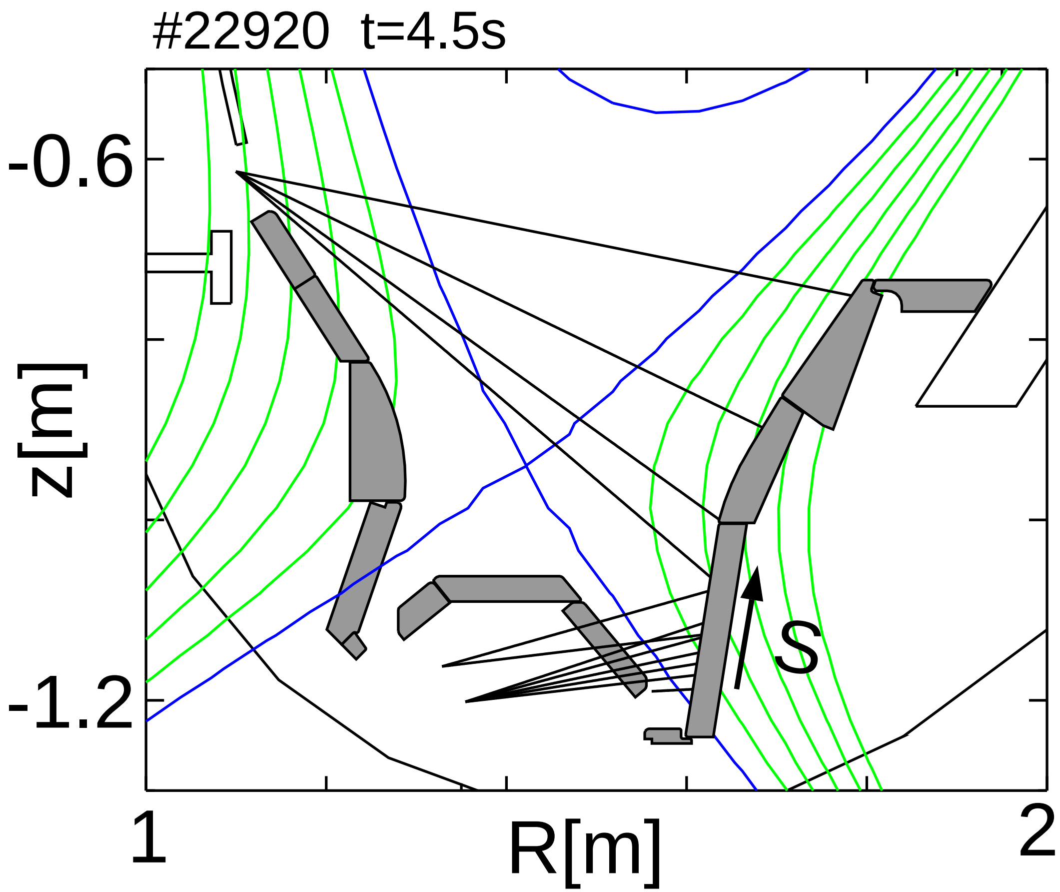




Measurement of Tungsten Erosion Fluxes in the Outer Divertor

observation of outer divertor
with 12 lines-of-sight
(7 lines-of-sight in 2007)

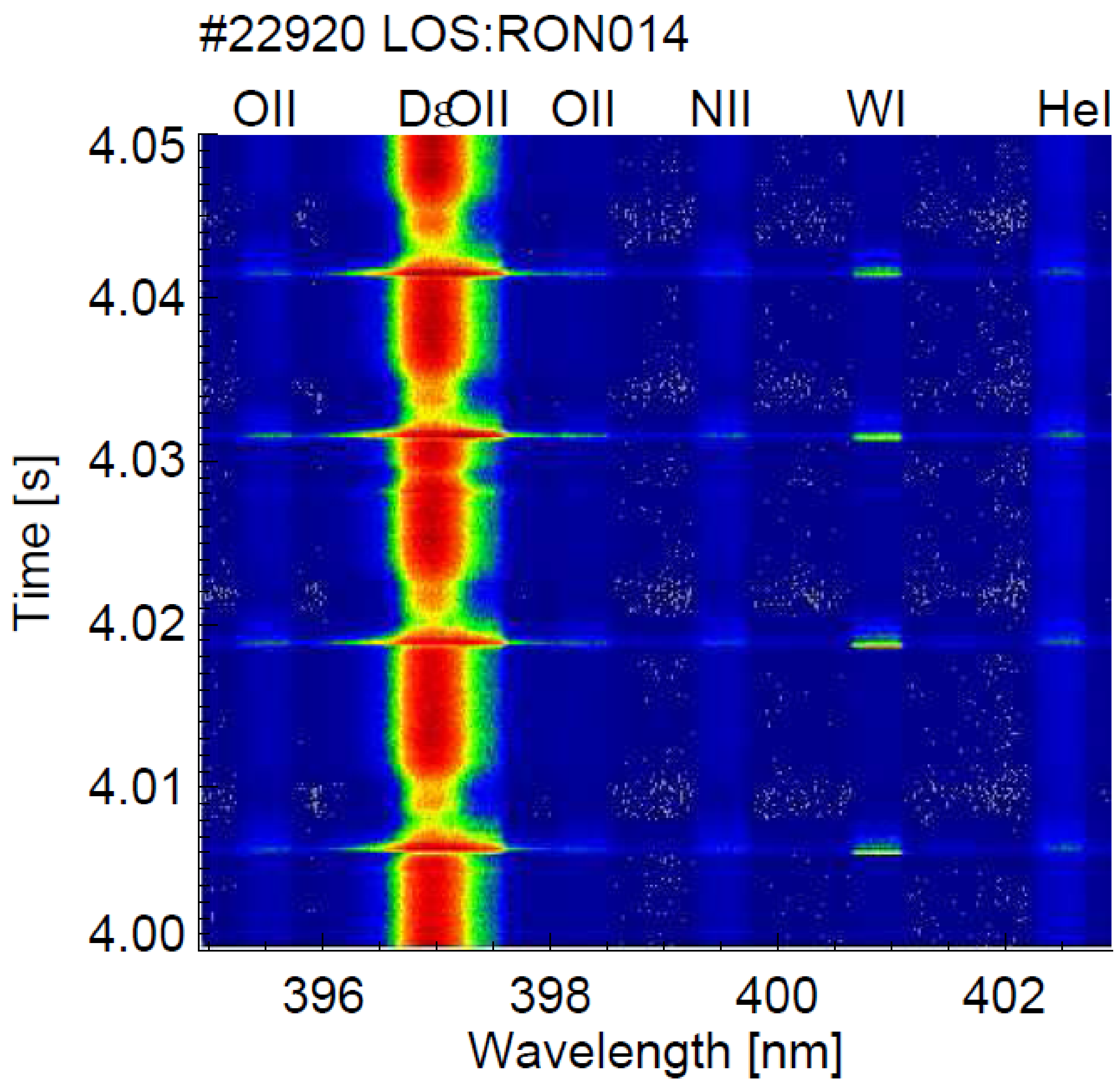
- 1 fast channel with Δt=200μs
- remaining channels with Δt=3ms
- WI line at 400.9nm
- W influx from photon flux
  using S/XB=20.



Example of spectra measured in the outer divertor

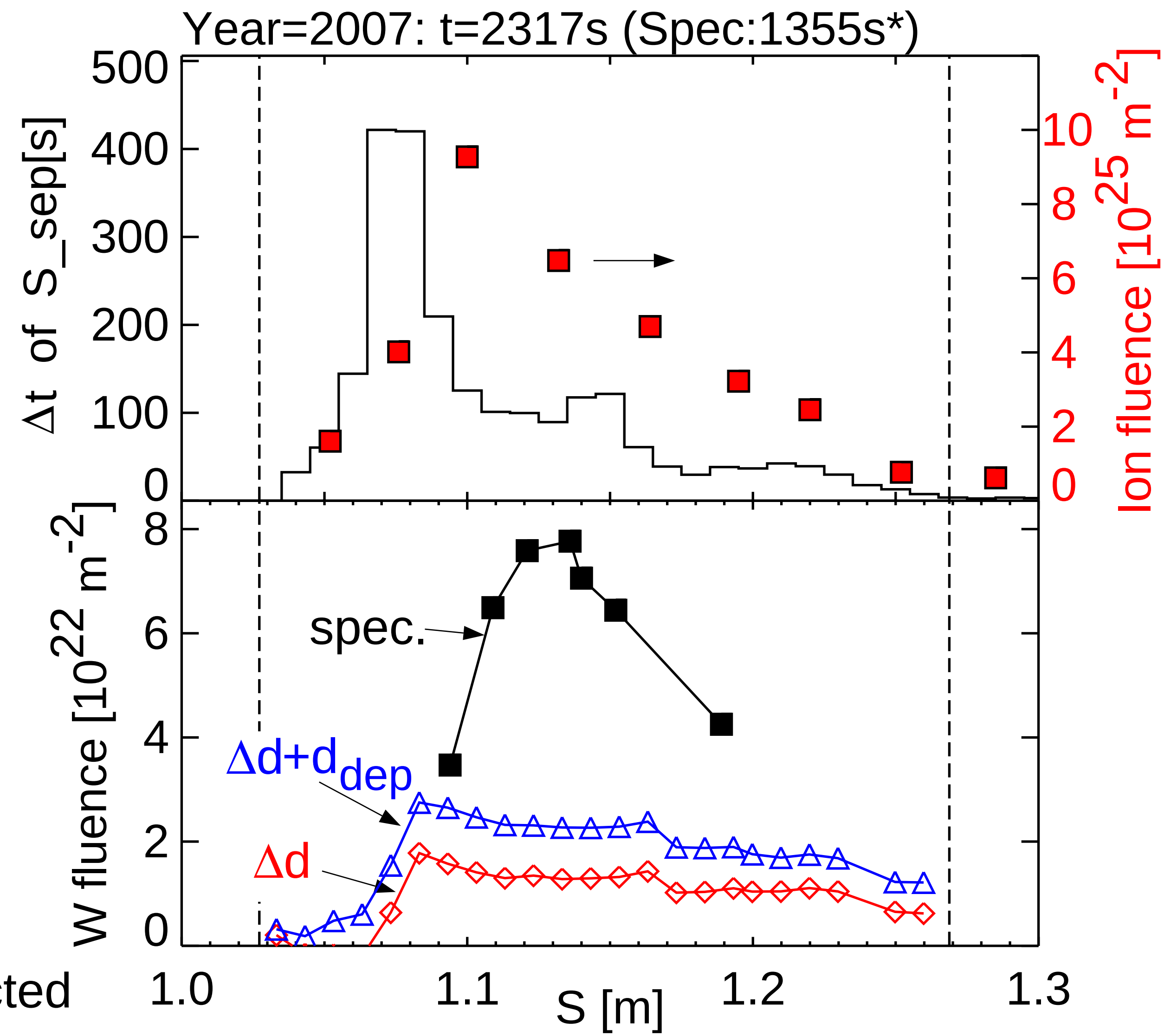
WI line:
weak but quite well separated

exposure time 200µs



Total Erosion in 2007 Campaign (check spectroscopy against surface analysis)

- change of layer thickness with RBS of a 1.5µm thick W-coating on C
- $\Delta d \approx 0.2$ µm (0.12nm/s) spatial average, microscopic variations due to surface roughness)
- compares well with spectroscopic erosion fluences (measure of all erosion events)
- data uncertainty of spec.about a factor of 2
- large prompt redeposition expected (typ. scales λ_ion=0.1mm, r_gyro=2.5mm)



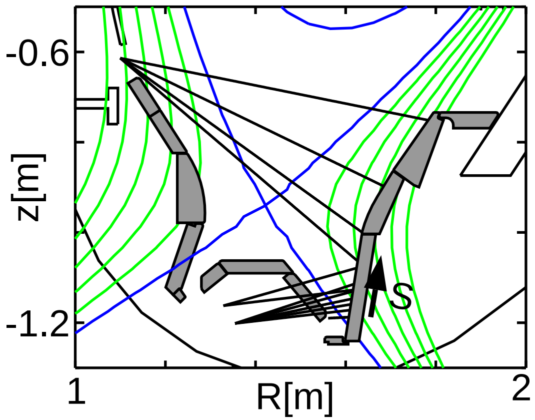
*spec. W fluence multiplied with: Δt_tot / Δt_measured

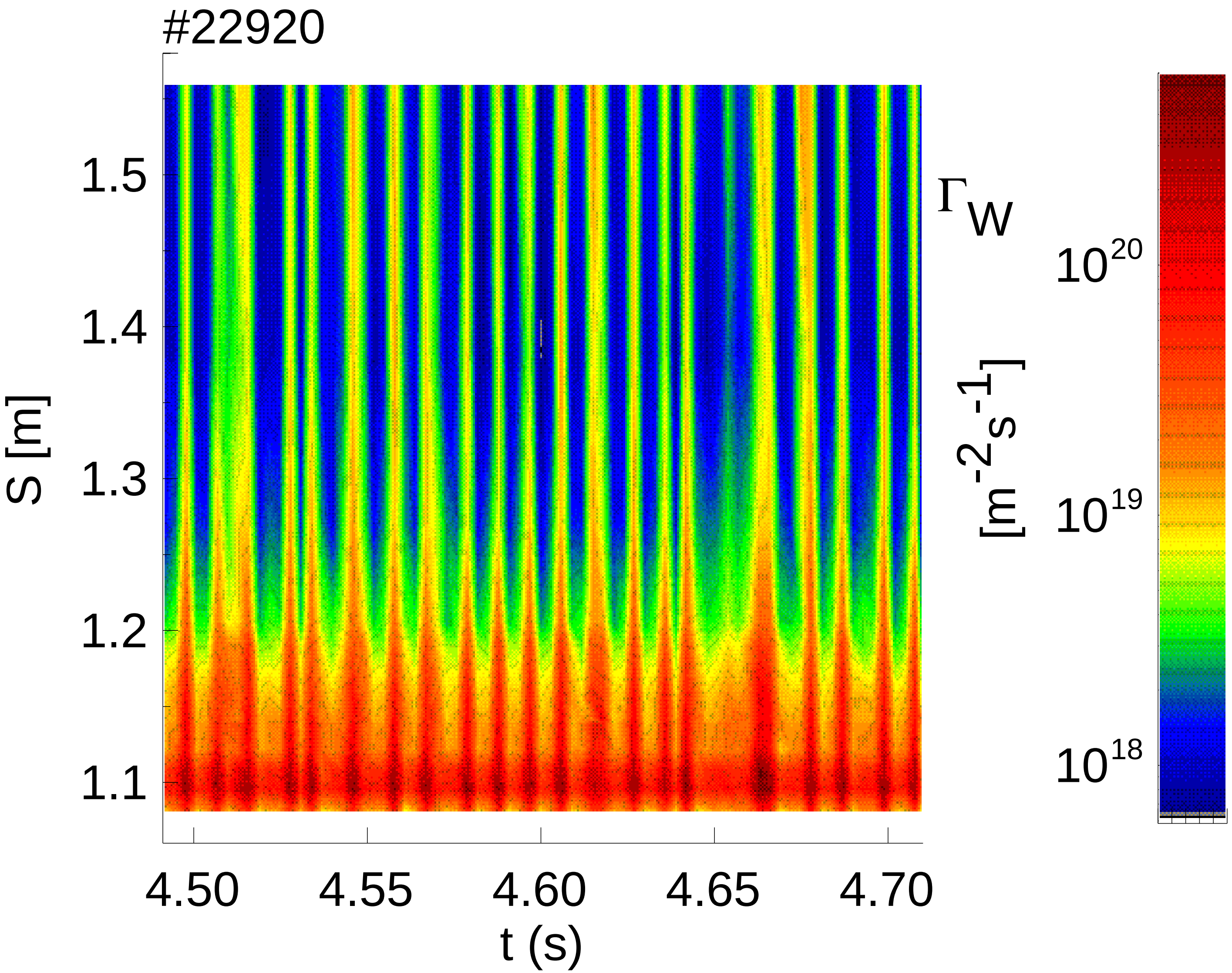
Time Resolved Profiles of Tungsten Erosion in outer Divertor

in H-mode plasmas:

- modulation of erosion profiles with arrival of energy bursts due to type-I ELMs

- time resolution (3ms) sufficient to measure erosion between ELMs





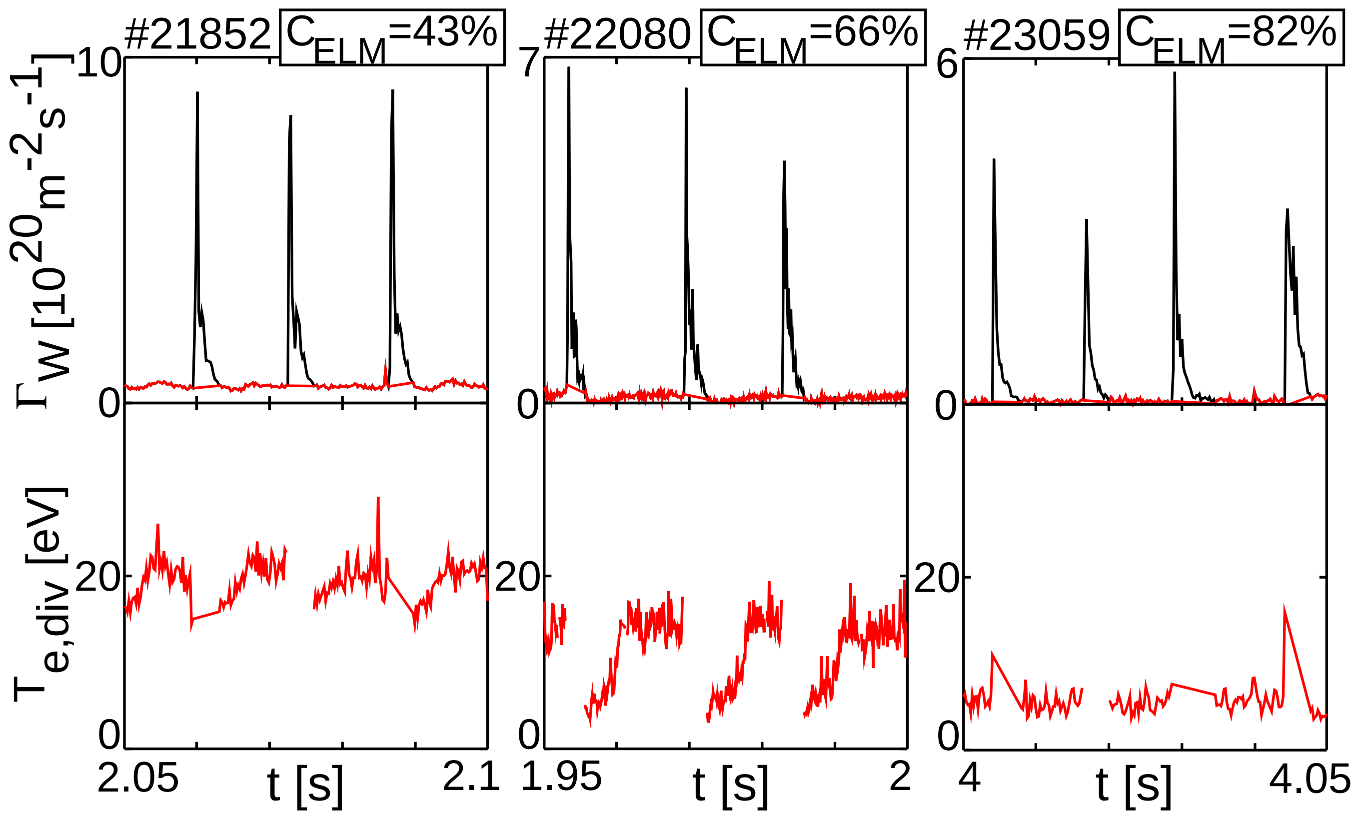
Fast measurement of local W-influx density in the outer divertor

Δt=200µs

- strong increase of influx density with ELMs

- between ELMs: influx decreases with electron temperature at target (recycling level, distance to strike point ...)

- overall ELM contribution c_ELM to average influx density varies from 40-90%



(Te,div from Langmuir probes)

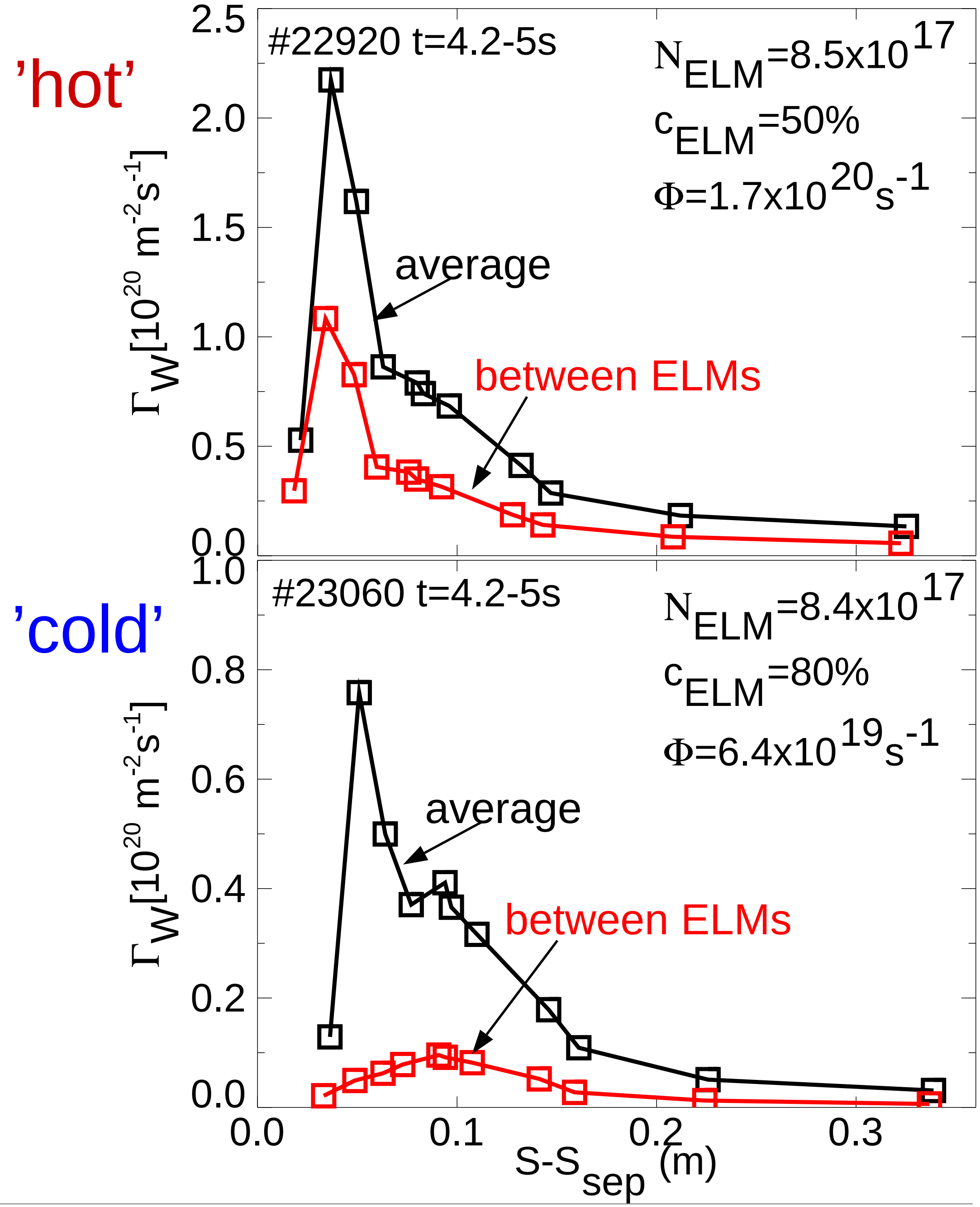
Tungsten Erosion Rates in the Outer Divertor

Profile Measurements

- hot divertor
  - T_e≈20eV near strike point
  - highest erosion rates (up to 2E20/s)
  - 50% erosion between ELMs

- cold divertor
  - T_e≈6eV near strike point
  - erosion dominated by ELMs (80%)

- number of eroded W atoms per ELM
  - rises with ELM energy (max. 1E18)
  - also here pure D sputtering not sufficient to explain erosion



Tungsten sources in the main chamber

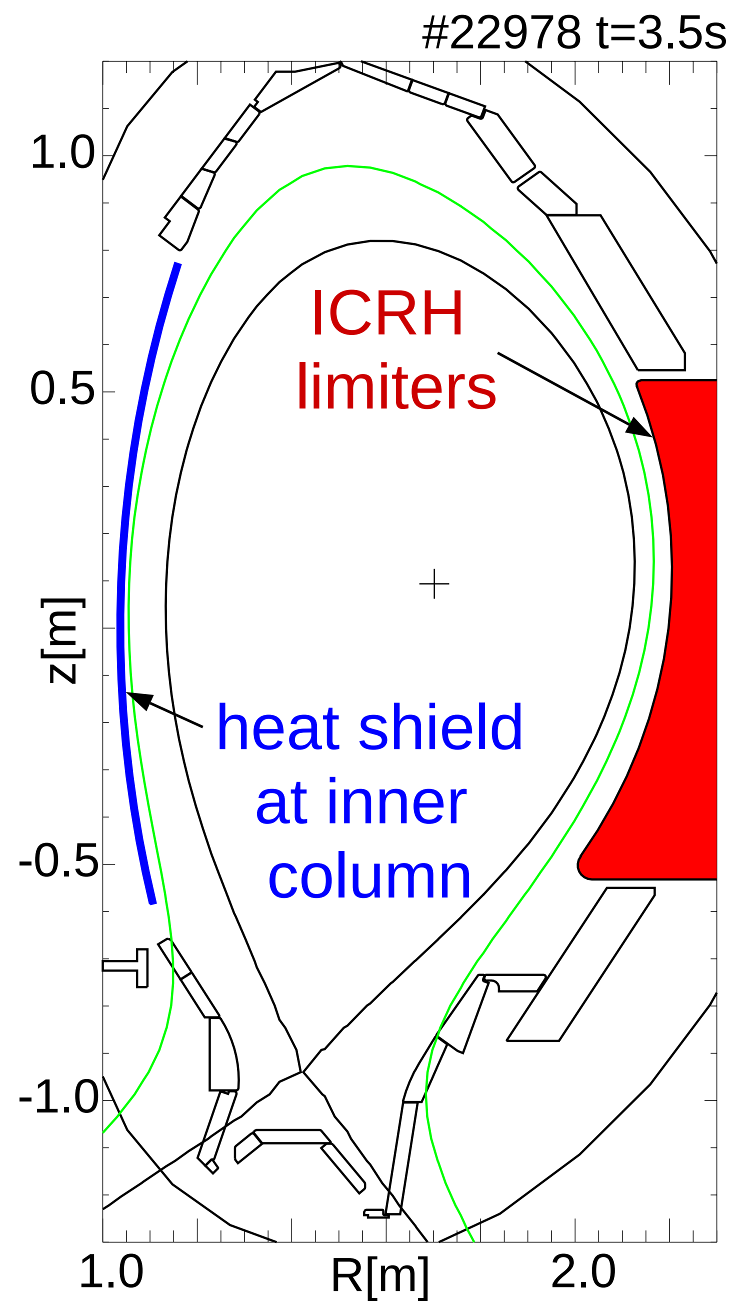
main erosion areas

High Field Side

- inner column
  - covered by a toroidally symmetric heat shield without protruding elements
  - largest area (8.5m**2)

Low Field Side

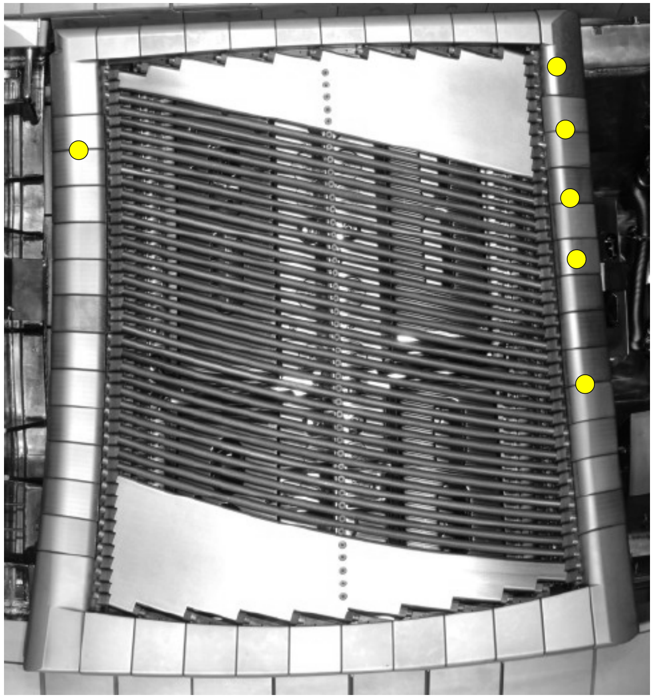
- window frames around the 4 ICRF antennas
- 4 limiters next to NBI ports

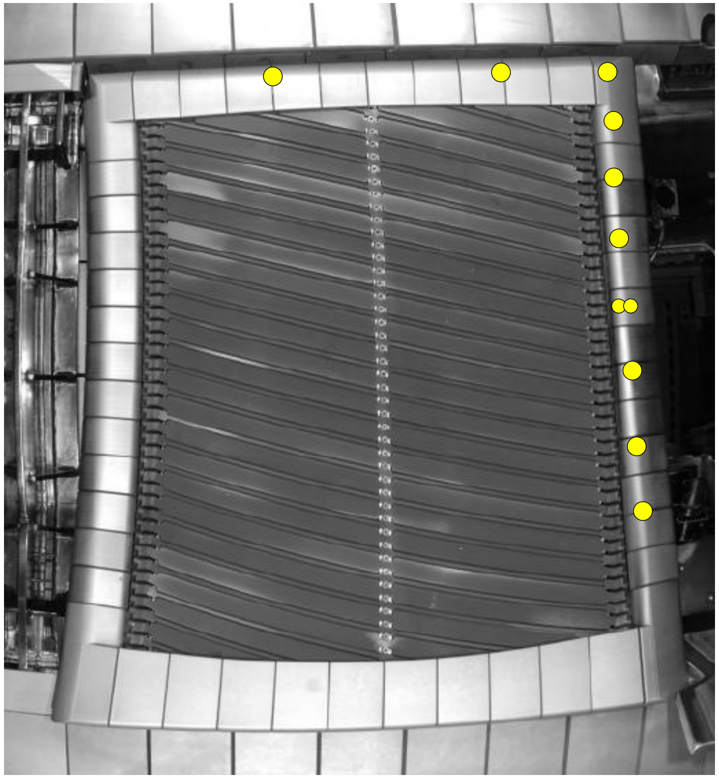


Spectroscopic observation of low-field side limiters

17 lines-of-sight
on window frames
around ICRF antennas

Δt=3.4ms

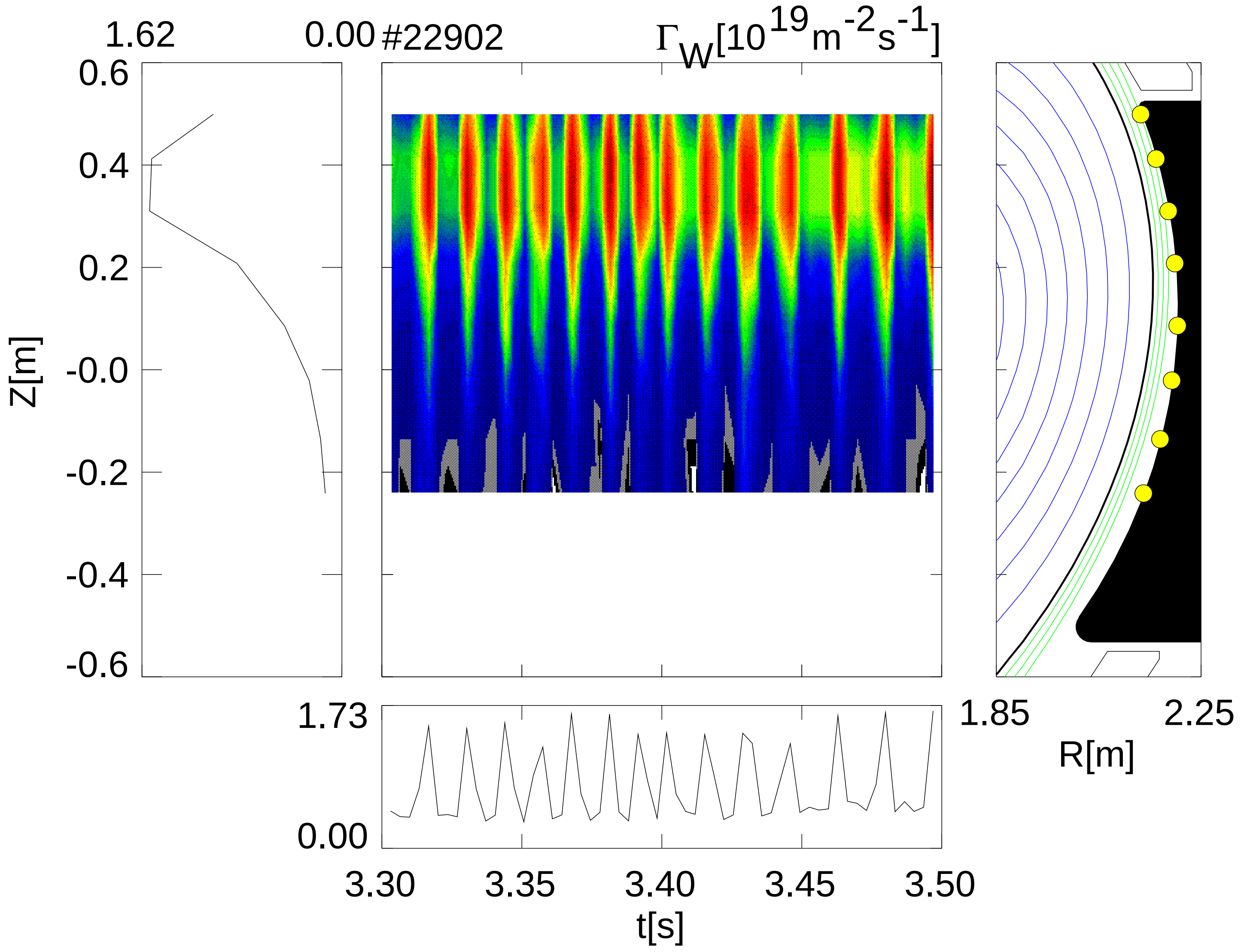




W Erosion profile along the poloidal ICRH limiter

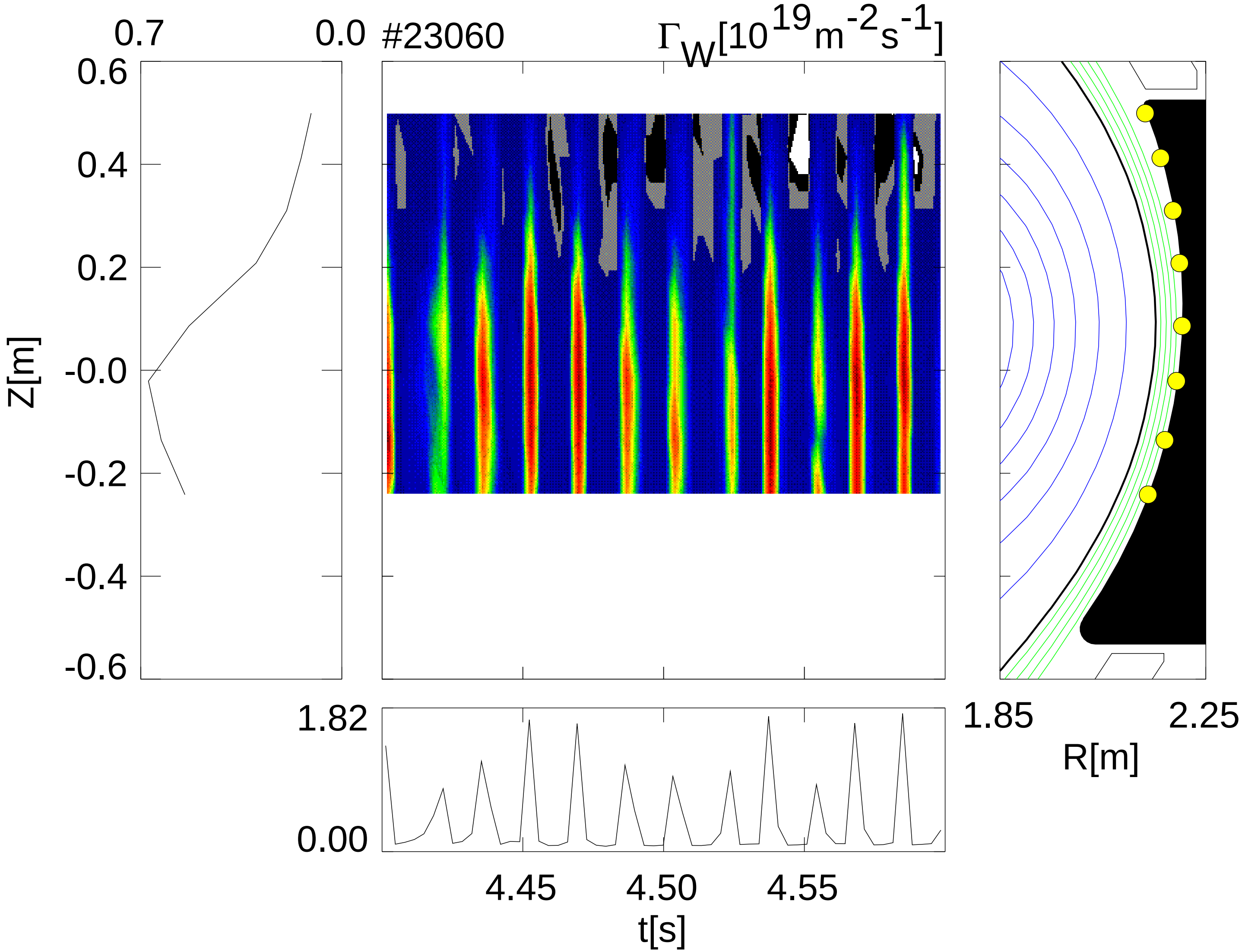
- contribution of ELMs to total erosion flux (70±10)%

- profile peaks at the position, where SOL plasma is limited
  - usually on upper part of limiter



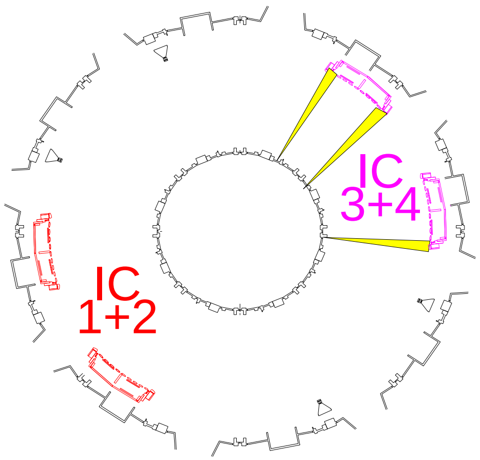
W Erosion profile along the poloidal ICRH limiter

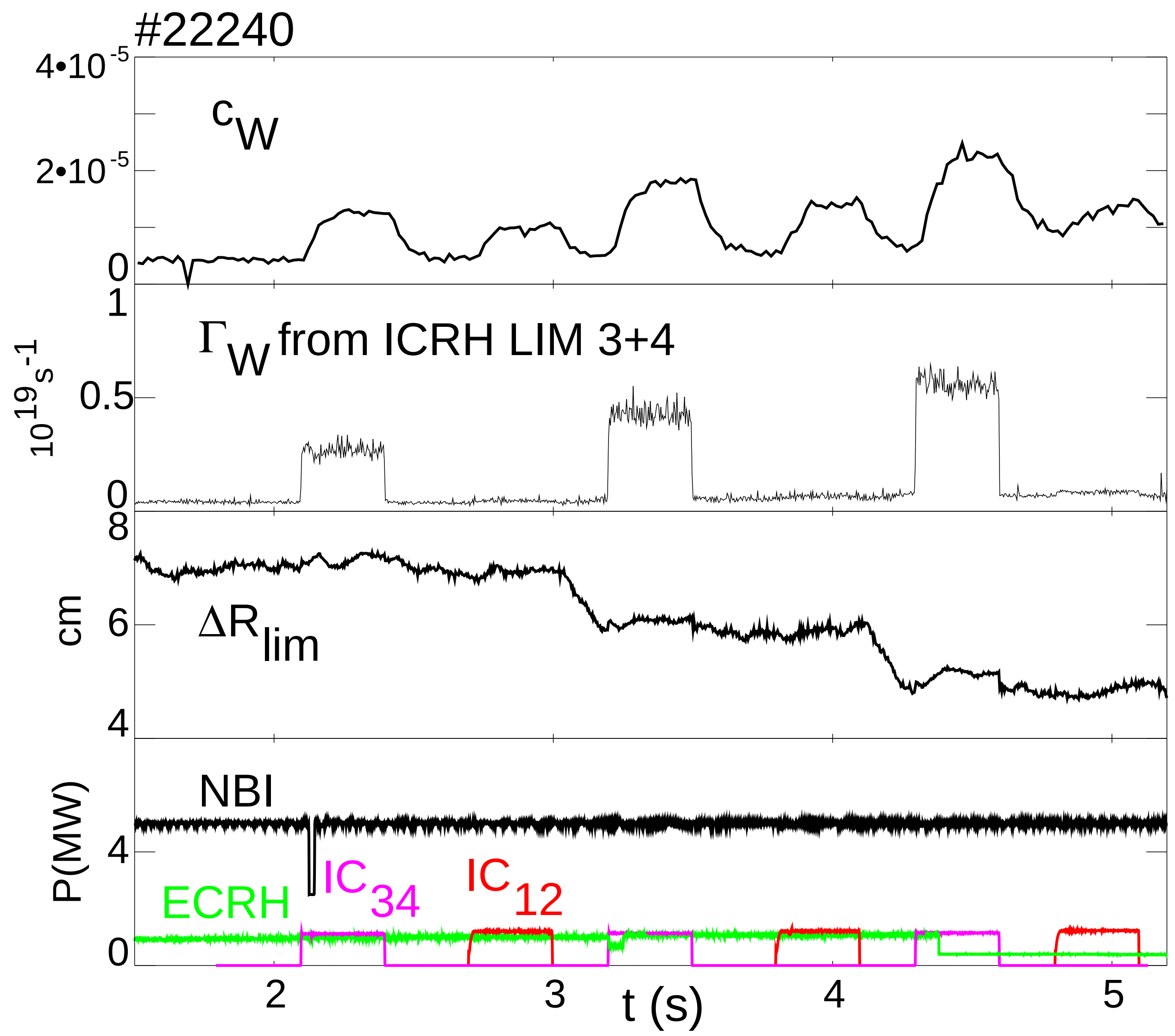
- contribution of ELMs to total erosion flux (70±10)%
- profile peaks at the position, where SOL plasma is limited
  - usually on upper part of limiter
  - in a few cases on the lower part of the limiter
- radial decay length in both cases ≈1cm



Increase of limiter source and tungsten concentration with ICRF

- ICRF heating causes strong increase of limiter erosion and tungsten concentration
- effect is due to increase of sheath potential drop causing an increase of the W sputtering yield
- optimization of ICRF antennas





Effect of Type-I ELMs on the W Erosion at the Limiters

ELM resolved measurements of total W erosion on:

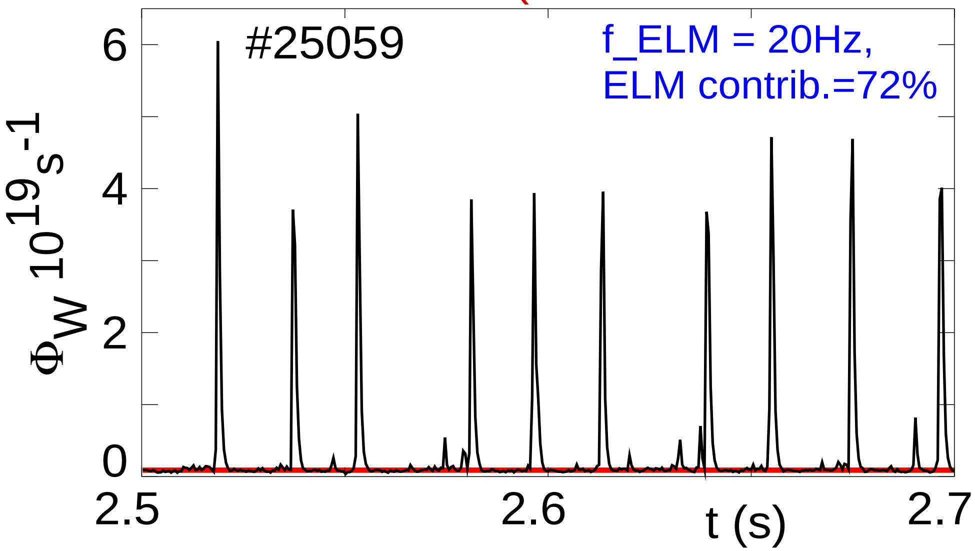
- inner column (Δt=1.2ms)
- outboard limiters (Δt=0.5ms)

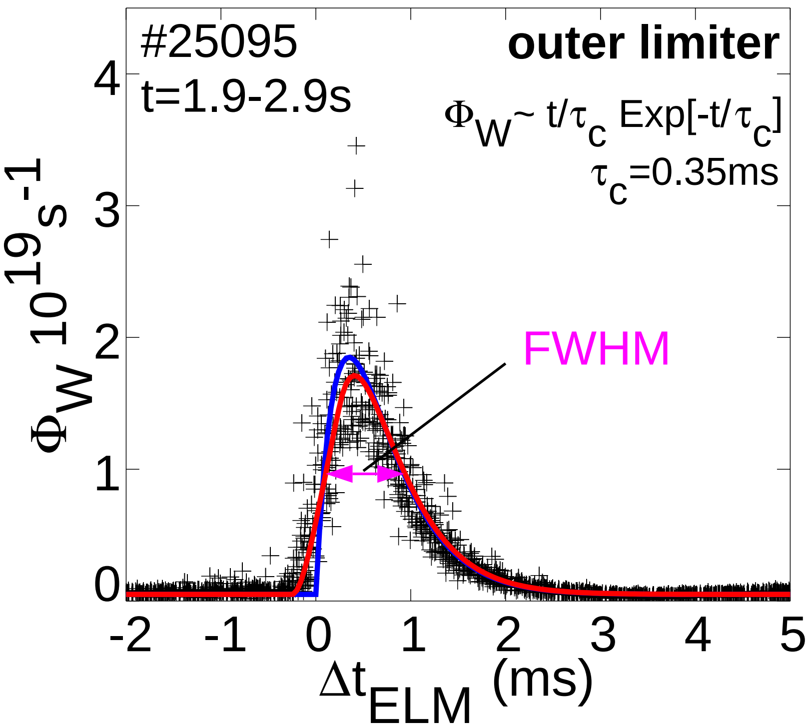
During ELMs drastic increase of W source at ouboard limiters by more than a factor of 10

mean temporal shape

- rise time ≈ 0.35 ms
- FWHM ≈ 0.85ms

Total limiter source (10 LOS with Δt=0.5ms)

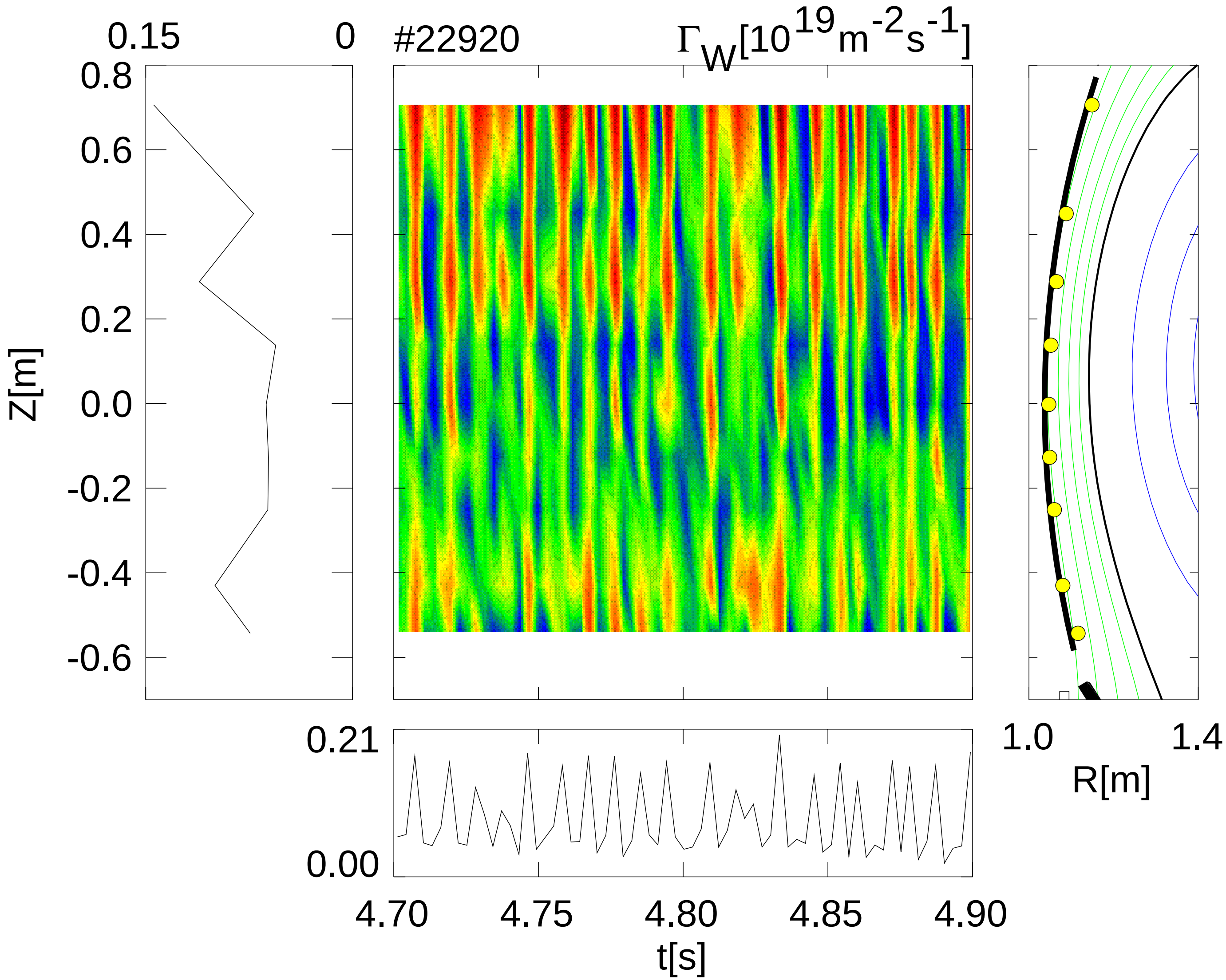




W Erosion profile along the inner column

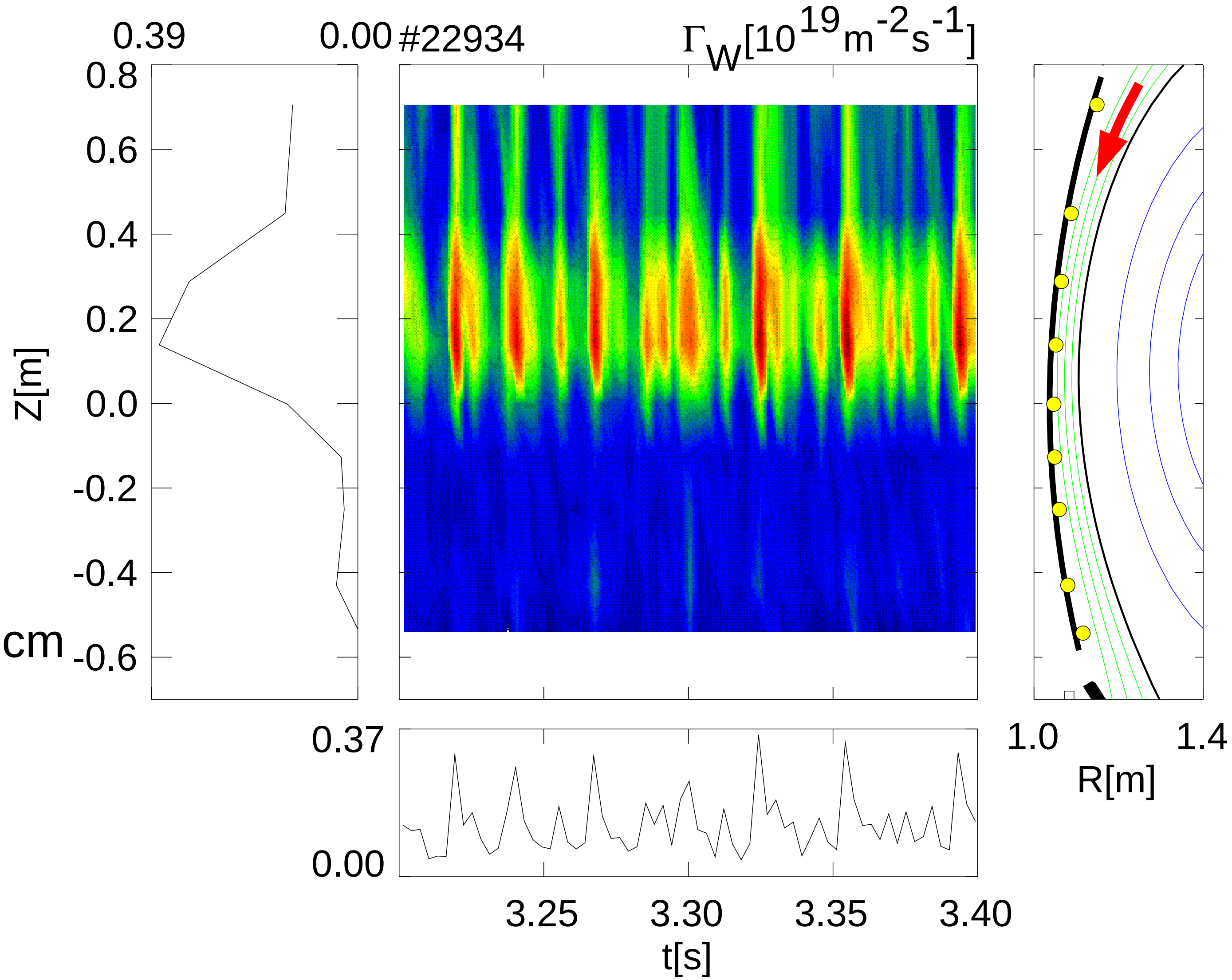
Δt=3ms

- flat erosion profile, if flux surfaces are well aligned with heat shield



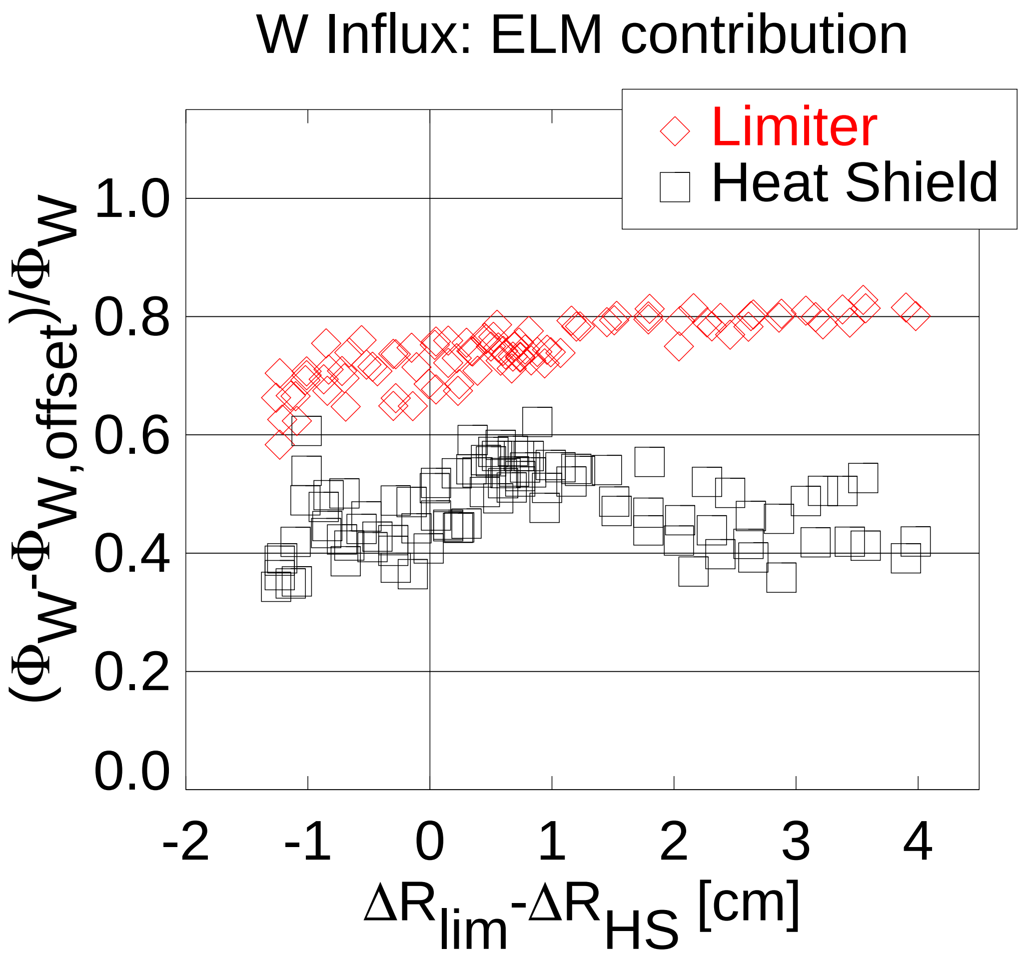
W Erosion profile along the inner column

- flux surfaces limited by heat shield contour at z=0.05 m
- main ion/energy loss of plasma at outboard side
- lower part is shielded
  - radial decay length ≈0.25cm



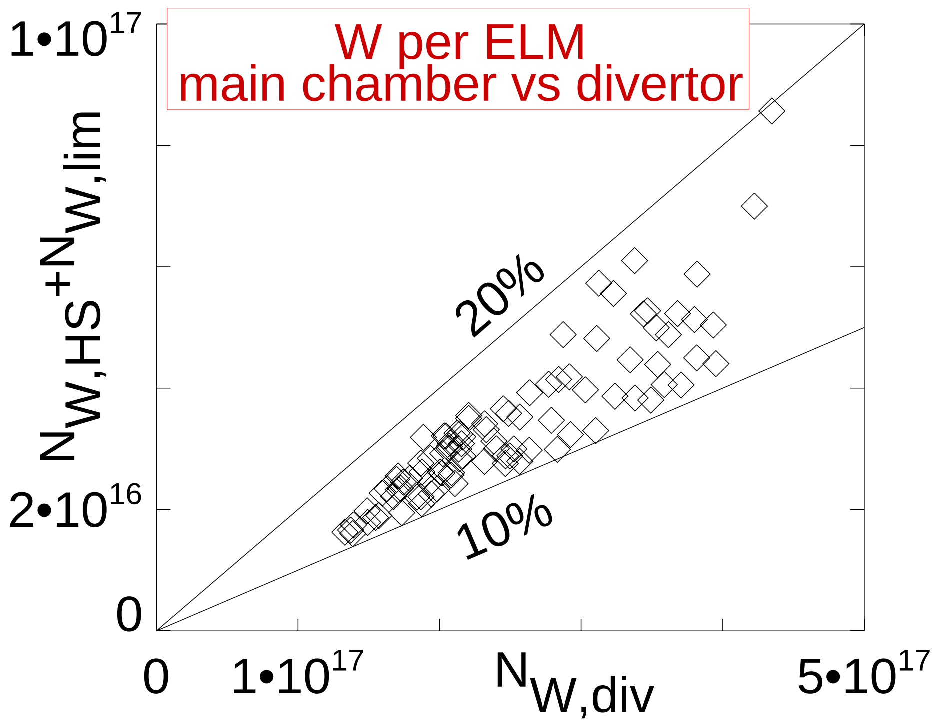
Contribution of ELM Erosion to Total W Source at Limiters/Heat Shield

- at limiters: 60-80%
- at heat shield: 40-60%
- smaller more frequent ELMs have same effect as larger less frequent ELMs



Balance of W Erosion during ELMs: Main Chamber versus Divertor

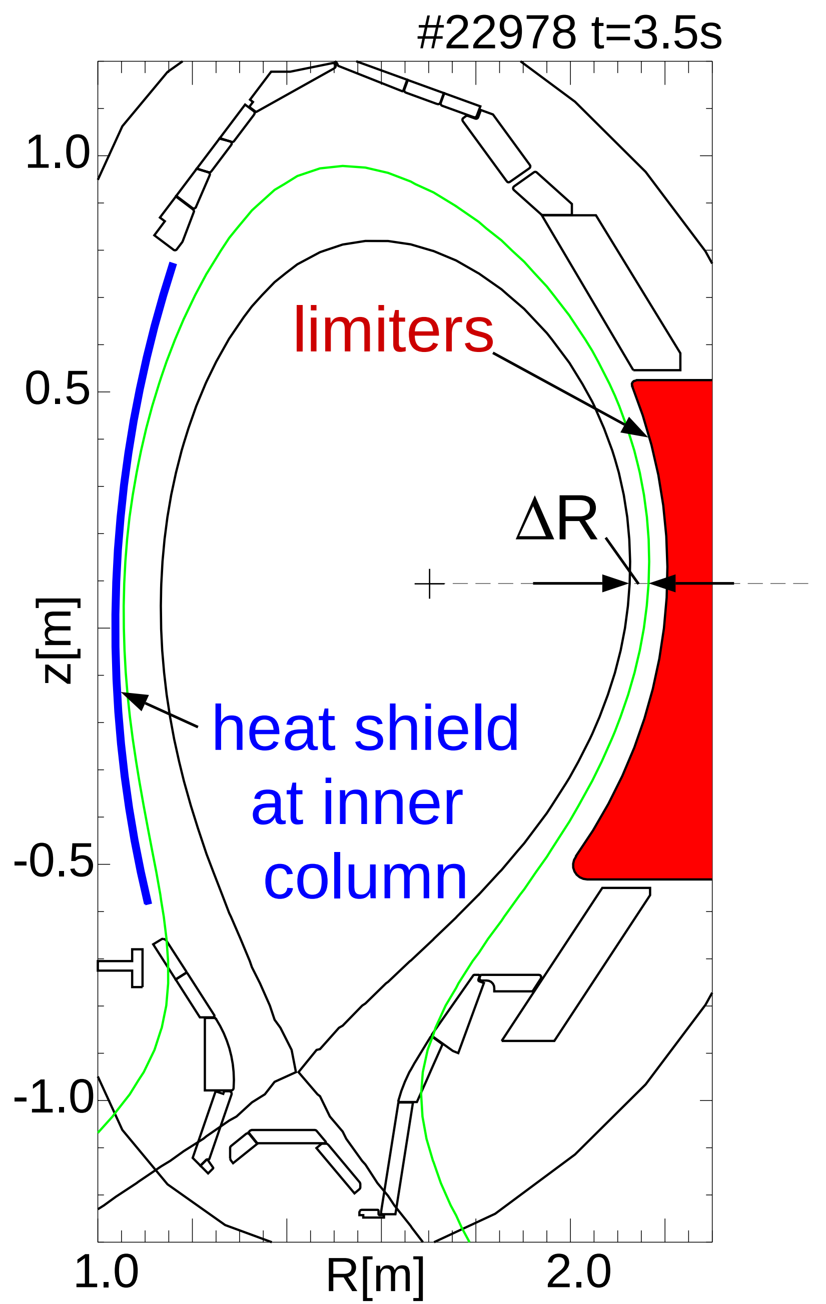
W erosion at main chamber PFCs releases 10-20% of the W atoms eroded in the divertor.



W source balance between heat shield and outboard limiters depends on distance to separatrix

flux surface label Δ**R**
- distance to separatrix measured on the outer equator

Expect the first limiting surface with lowest ΔR to be the predominant W source

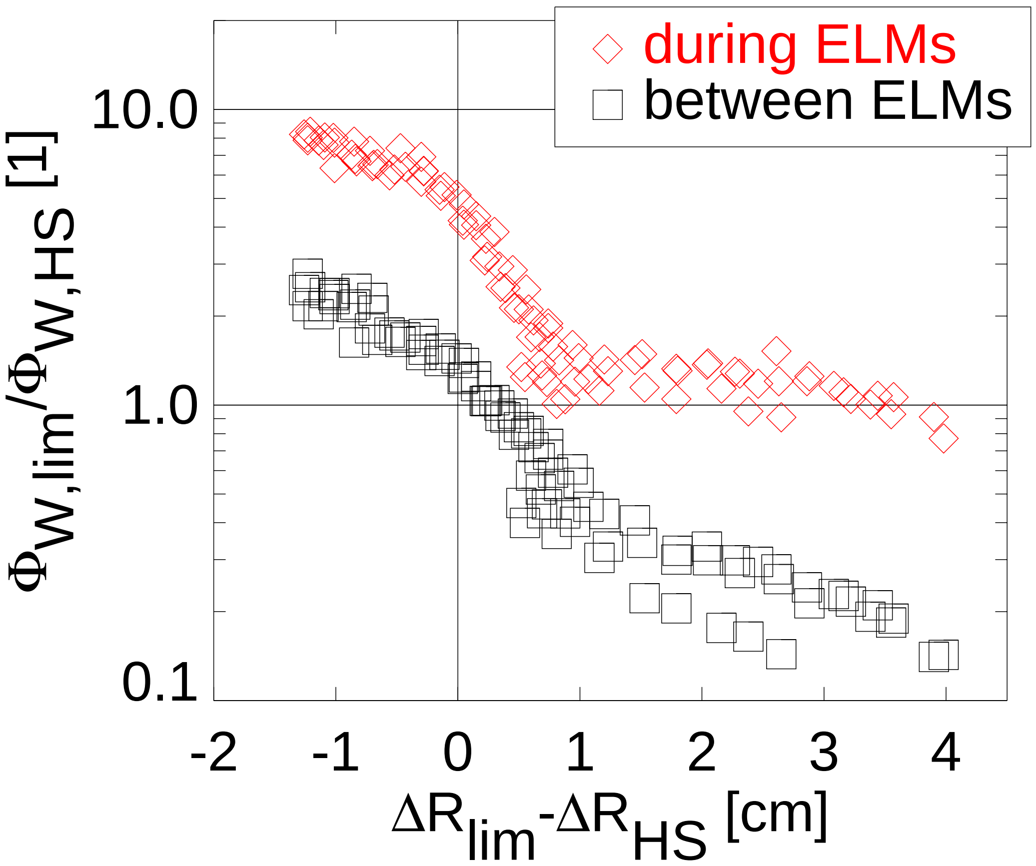


W Source Balance between Heat Shield and Outboard Limiters

- between ELMs the balance is in acordance with a parallel loss onto the first limiting element (within uncertainties of the magnetic equilibrium and the erosion measurements)

- during ELMs the balance is shifted to the outboard side (filaments)

ratio of W influx limiter/heat shield versus radial position of the plasma column



Erosion Yield for Physical Sputtering

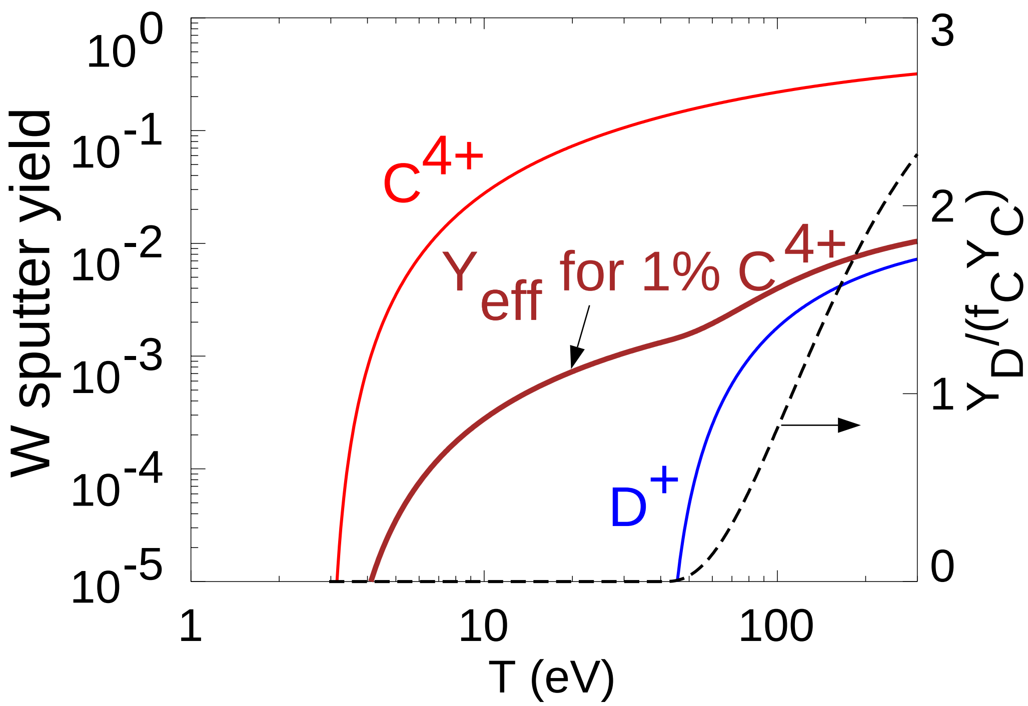
simple estimate of ion energy
$$E = 2\,k_B T_i + 3\,Z\,k_B T_e$$

In the relevant temperature range W sputtering is mainly caused by light impurities

since impurities have
- a higher mass
- and a higher energy gain in the sheath (Z>1)

High tungsten influx expected for large temperatures → ELMs

W erosion yields for sputtering by D and C

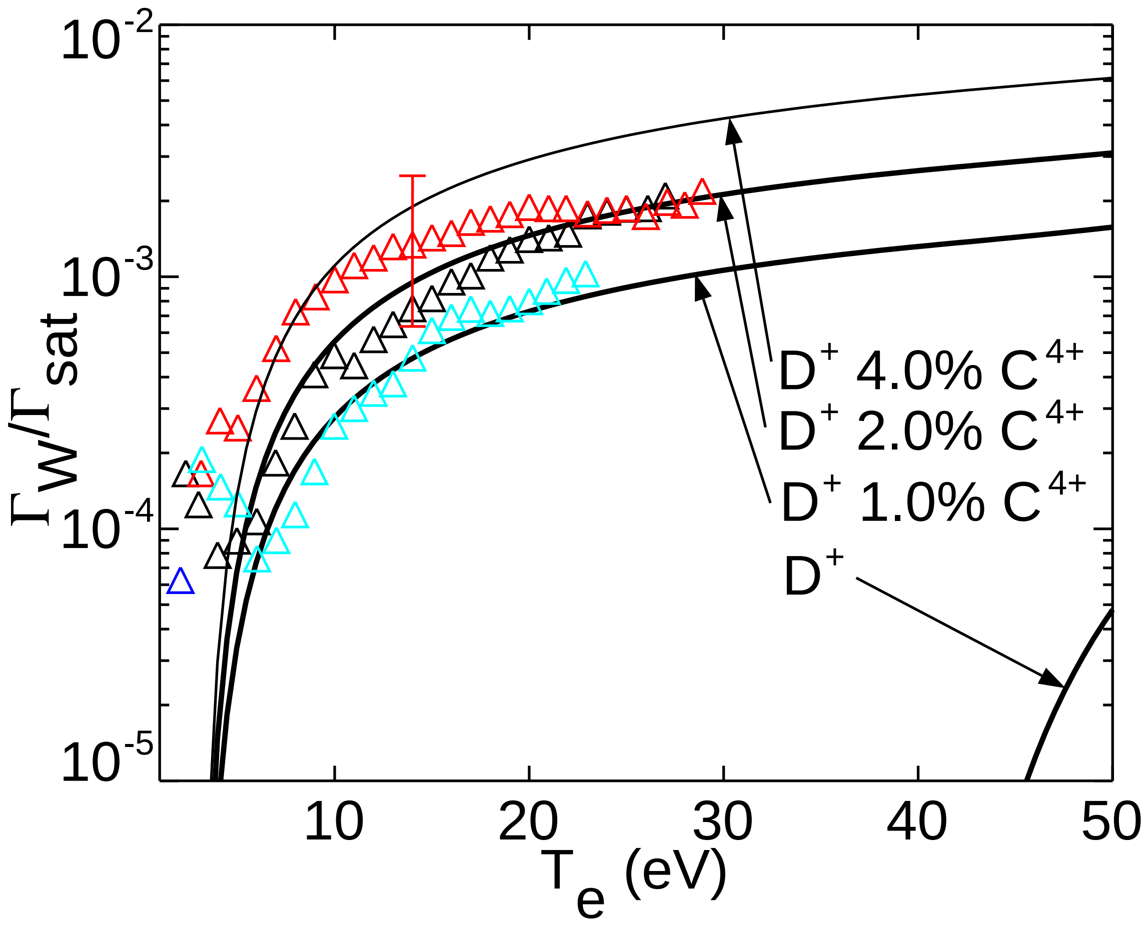


Effective erosion yield between ELMs

between ELMs

- ratio of tungsten influx density to the ion saturation flux yields a measure for the effective erosion yield (estimated systematic error ± factor of 2)

- effective yield as function of T_e at target can only be understood for dominant erosion by impurity ions



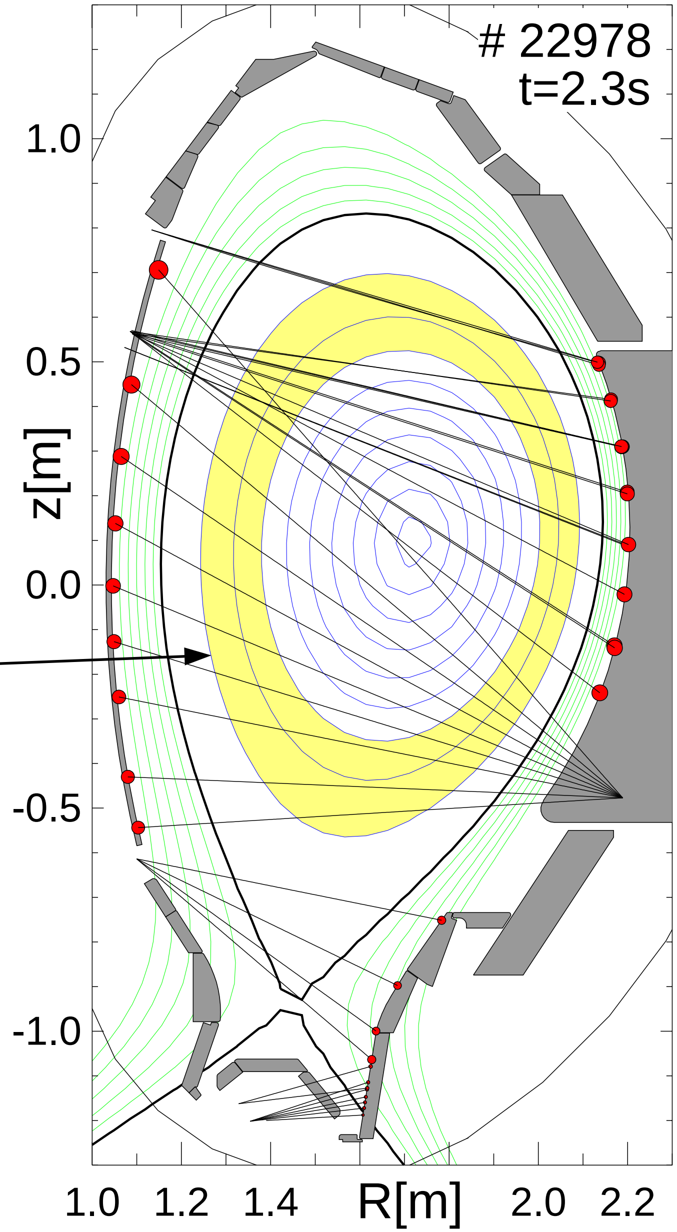
Measurement of Tungsten Source and Confined Tungsten Density

Source of neutral W from all major erosion areas

- WI line at 400.9nm
  - heat shield: 9 lines-of-sight
  - outer limiters: 17 lines-of-sight
  - outer divertor: 12 lines-of-sight

W density in confined plasma

- W quasi-continuum at 5nm emitted by ion stages existing around T≈1.5keV typ. r/a ≈0.8



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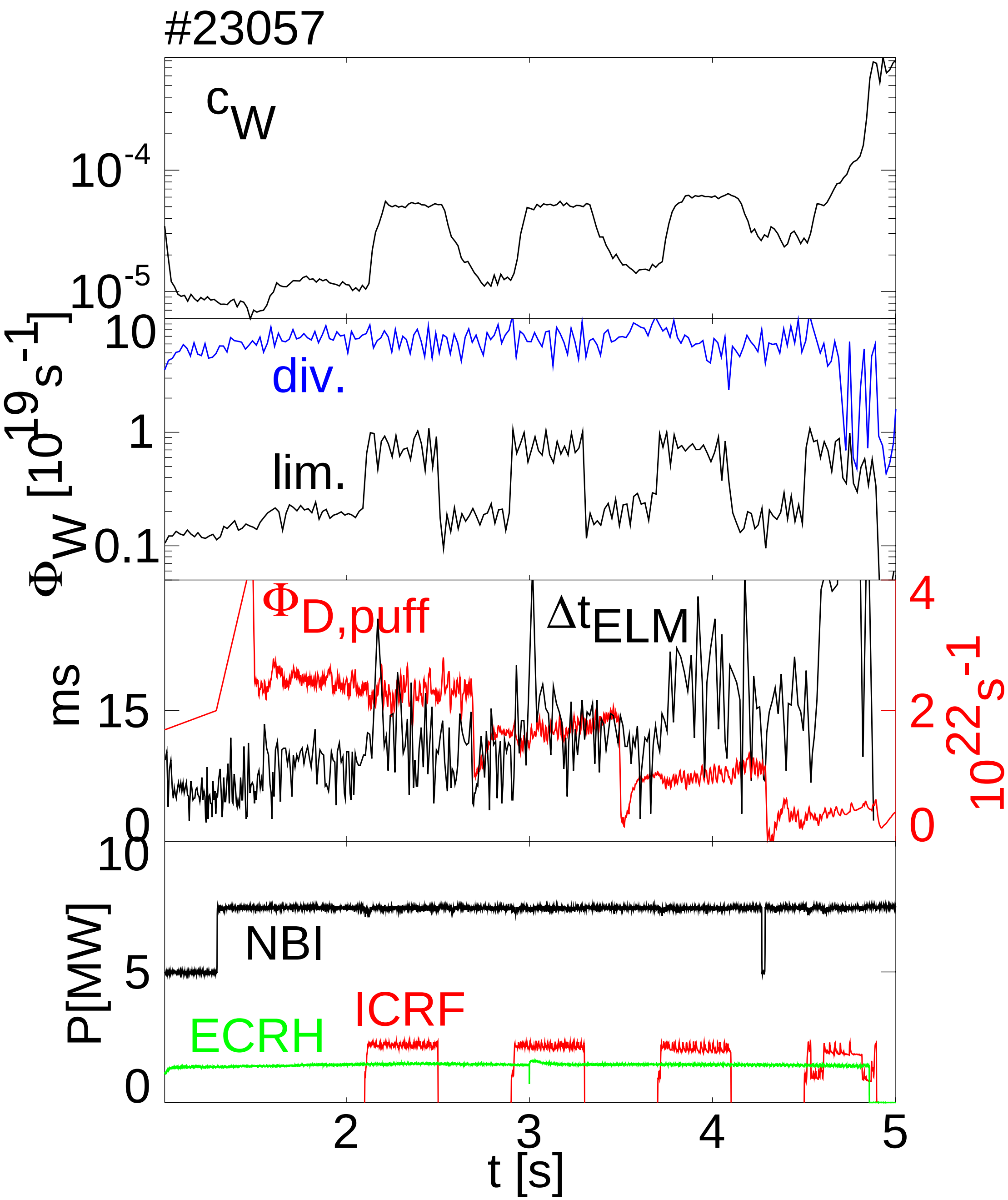


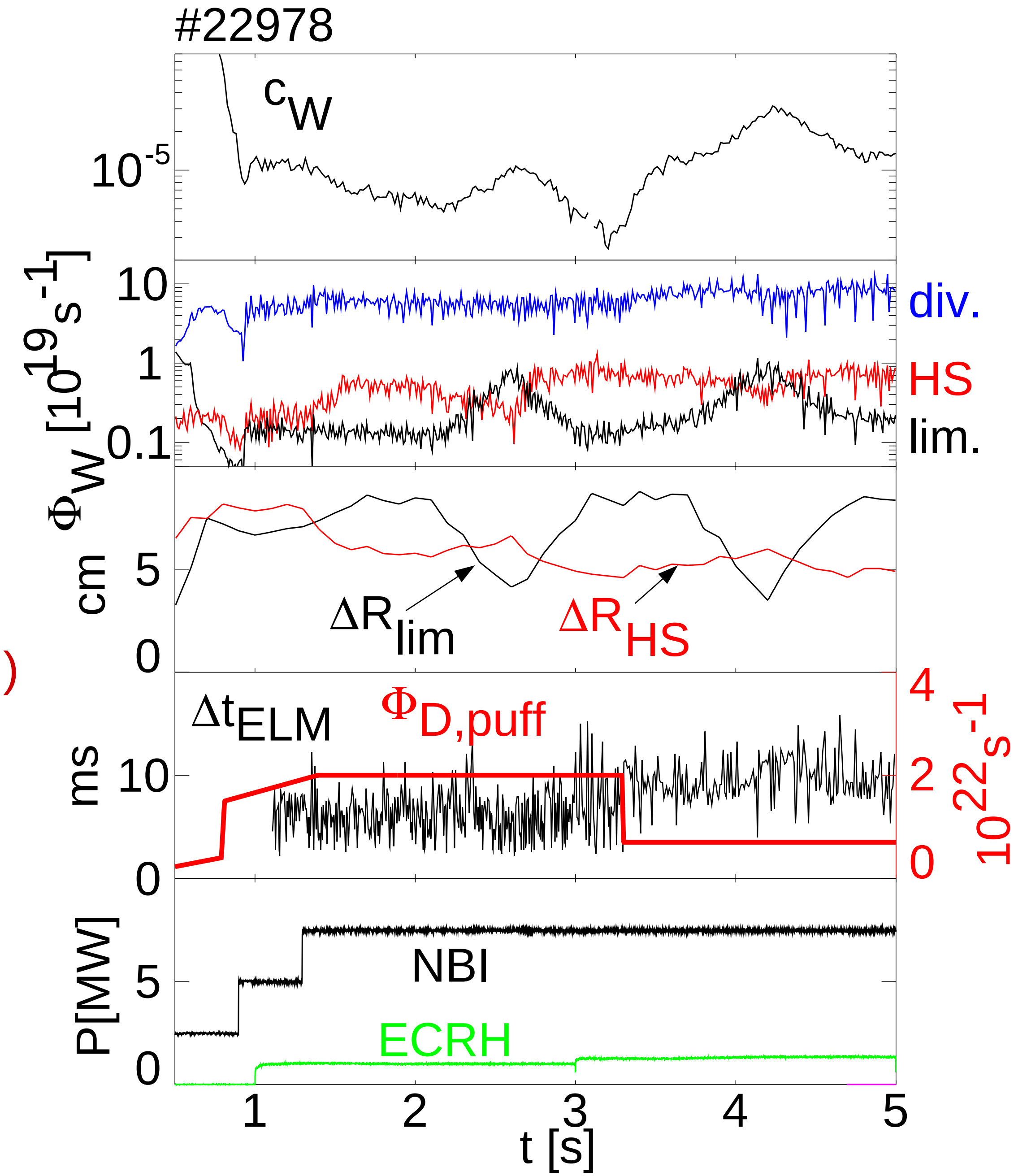
Comparison of different PFCs: Source Strength and Effect on W Concentration

radial sweeps of outer plasma radius at two puff levels

divertor source dominant

tungsten concentration modulates with the limiter source

mean tungsten concentration increases with the ELM period (ELM period is controled by puff level)



Summary

Fast spectroscopic W influx measurements
at all major erosion areas in ASDEX Upgrade

- give insight into the main mechanisms, which cause erosion of tungsten at the plasma facing components.

- are necessary to identify the dominant effects of different operation modes onto the sputtering of tungsten.

- are the basis for an understanding of the transport of W from the plasma facing component into the confined plasma.

  - A major goal is to understand the tungsten confinement in a fusion plasma ($\rightarrow$ see next talk by T. Pütterich).