ASDEX Upgrade

Max-Planck-Institut
für Plasmaphysik

IPP

Tungsten as First Wall Material in ASDEX Upgrade

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EX 3-3Ra

The Implications of a High-Z First Wall Materials on the Noble Gas Wall Recycling

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EX 3-3Rb

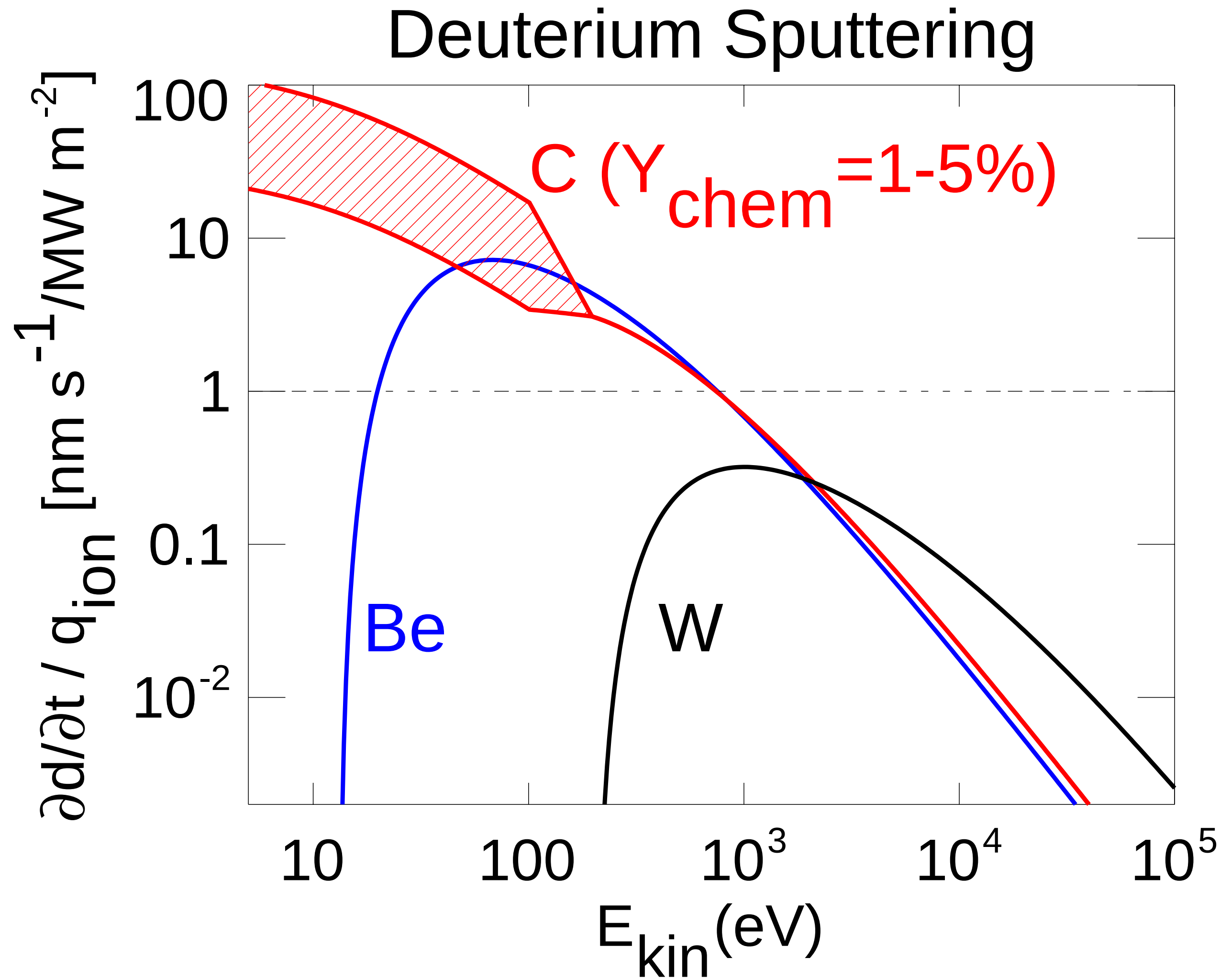
Rapporteur: R. Dux

Low Erosion Rates of Tungsten
→ Main Rational for W as Plasma Facing Material

for low ion energies
W has much lower erosion rate than low-Z elements

however
W induces a lot higher central radiation loss than low-Z elements

limit for central concentration in a reactor ≈ 10^{-4}



Steps in ASDEX-Upgrade towards a Full W-Device

since 1999
steady increase of W-PFC area

new for 2005/06 campaign
- all poloidal LFS guard and ICRH limiters
- lower PSL
- divertor roof baffle

(all 3µm W-PVD)

⇒ 35.9 m^2 (85% of PFC area)

for 2007 campaign
divertor strike point modules (VPS 200µm)

Long term evolution of Carbon concentration

Erosion of Tungsten at the low-field side limiters

- effect on Tungsten concentration
- sputtering by sheath accelerated impurity ions during ICRH
- sputtering by fast ions from NBI heating
- sputtering during ELMs

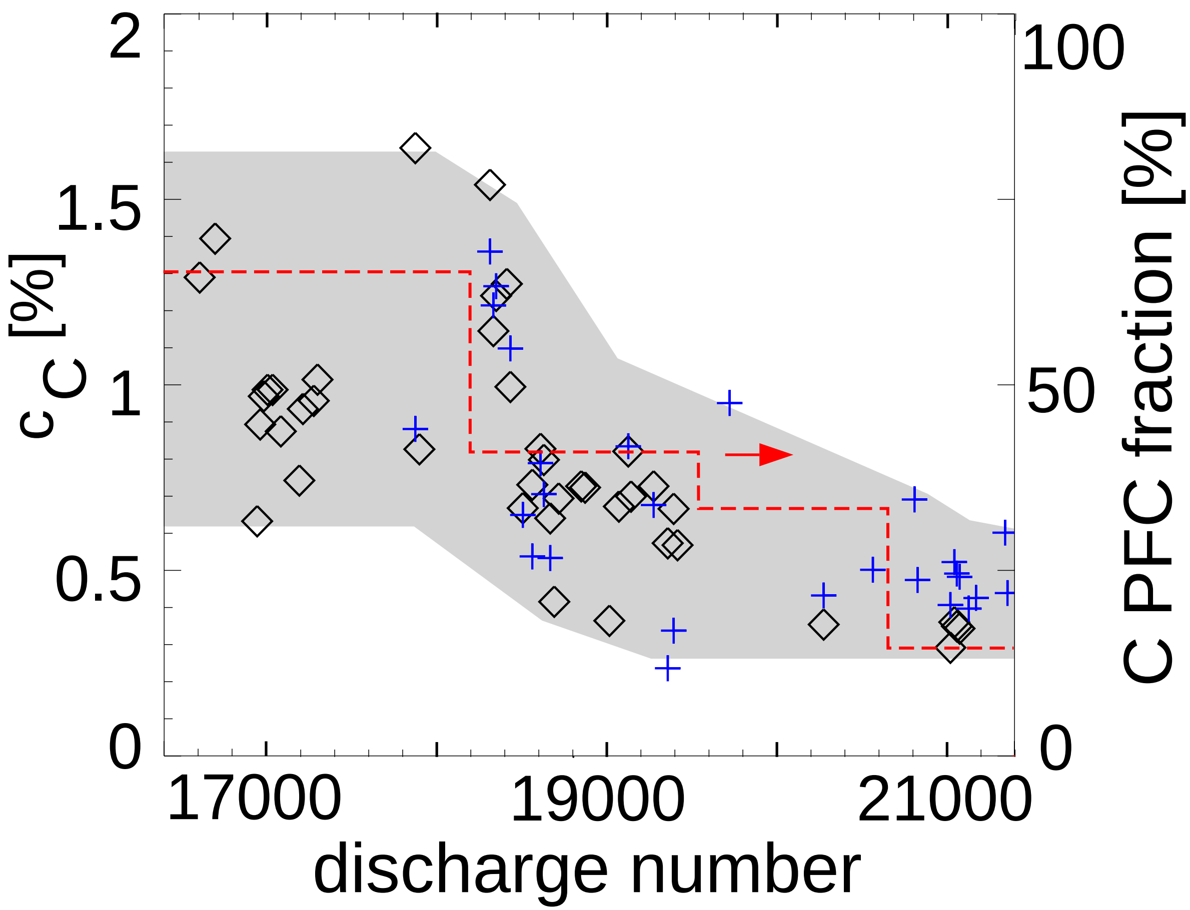
Implications of W-PFC on Helium Recycling

- observations at ASDEX Upgrade
- related laboratory experiments on He retention/release

Long term evolution of Carbon concentration

’standard’ H-mode discharge
with 5WM NBI at high density

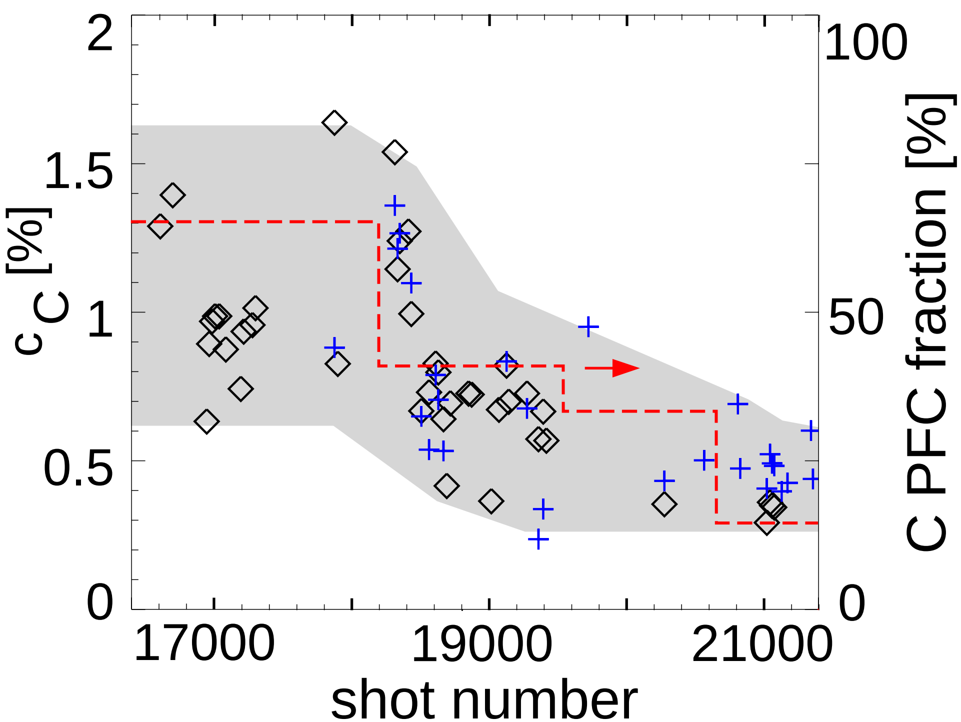
- considerable scatter (discharge history, operational and diagnostic imperfections)
- last campaign: carbon concentration reduced by about a factor of 2

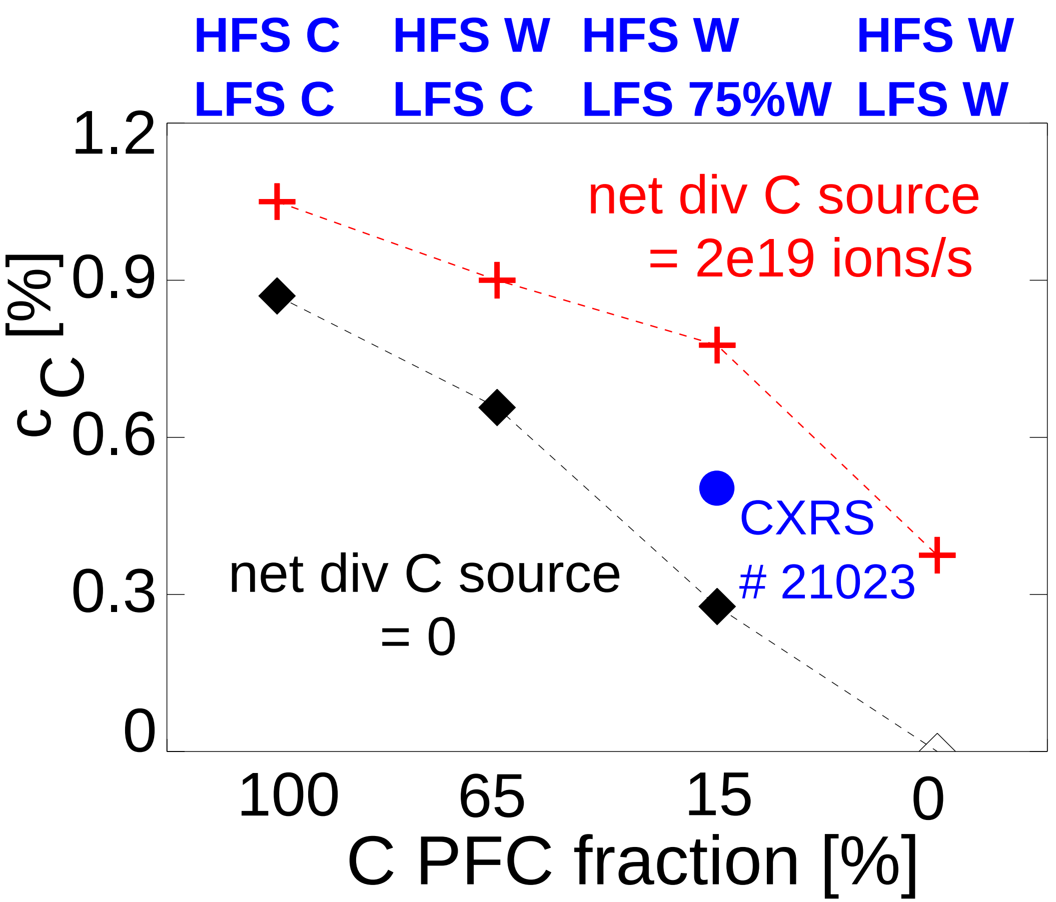


Long term evolution of Carbon concentration

Transport-Migration model for C

- slow evolution due to strong recycling of C
- reduction of net erosion sources (LFS limiter) now clerarly visibly
- remaining net erosion source: outer divertor (≈1E19s^-1 for this type of discharge)





Spectroscopic setup for W measurements

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Flux measurements at LFS limiters

- optical heads behind heat-shield observe limiters on 15 lines-of-sight
- WI (400.8nm), DI (410.1nm), BII (412.3nm)
- 3ms (all lines-of-sight), 250µs (1 line-of-sight)

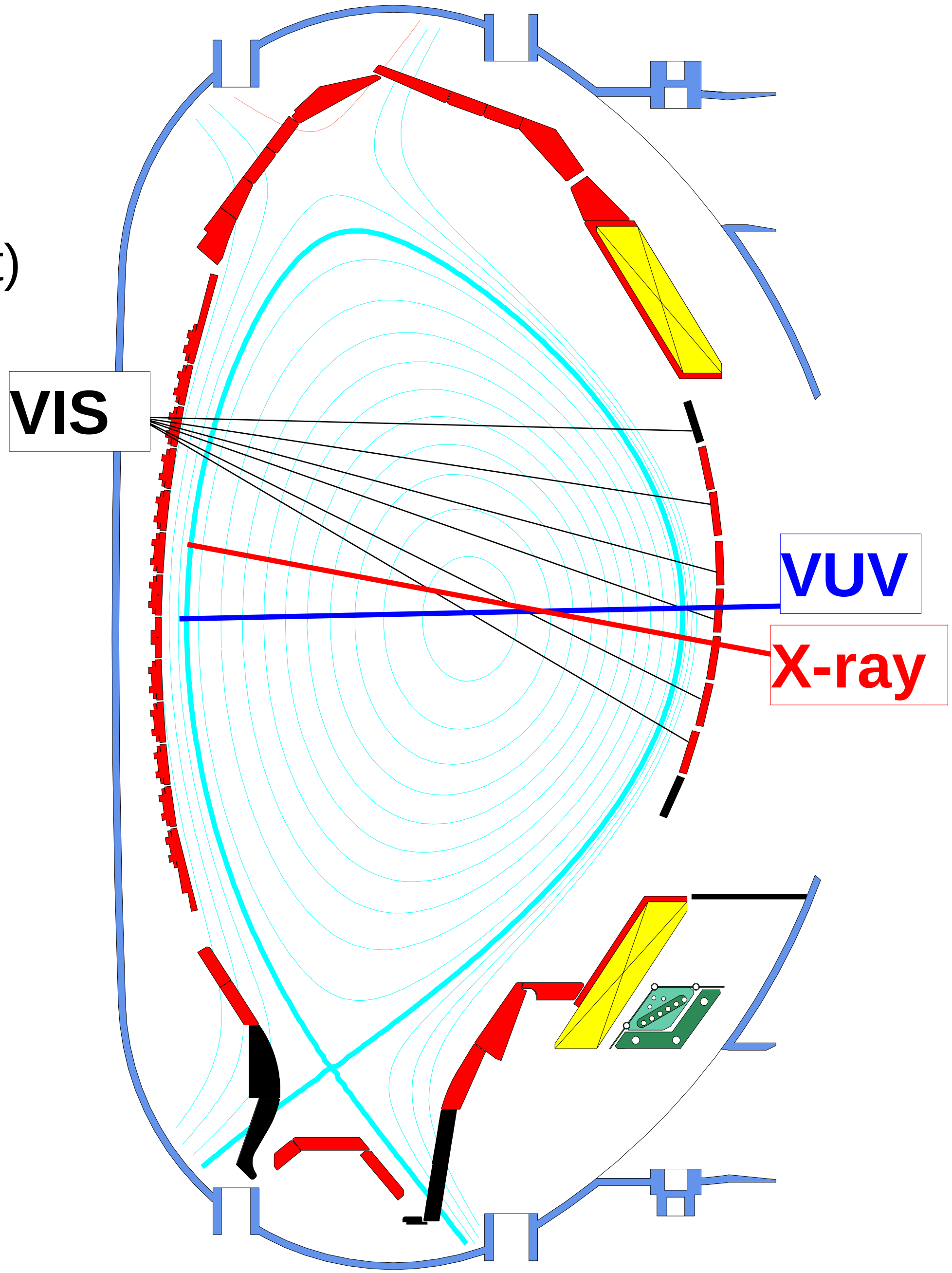
Concentration measurements

center

- Johann spectrometer W^{46+}(0.793nm) emitted at $T_e \approx$ 3keV

r/a ≈ 3/4

- grazing incidence spectrometer ≈ W^{28+}(quasi-continuum at 5nm) emitted at $T_e \approx$ 1keV

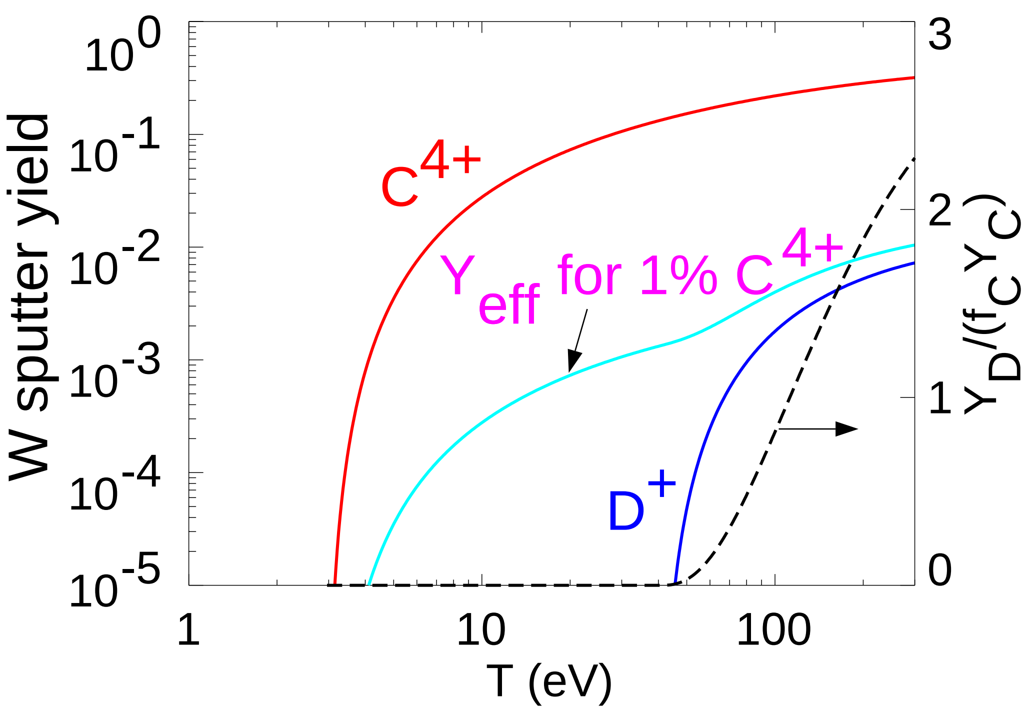


Erosion yields for physical sputtering of Tungsten

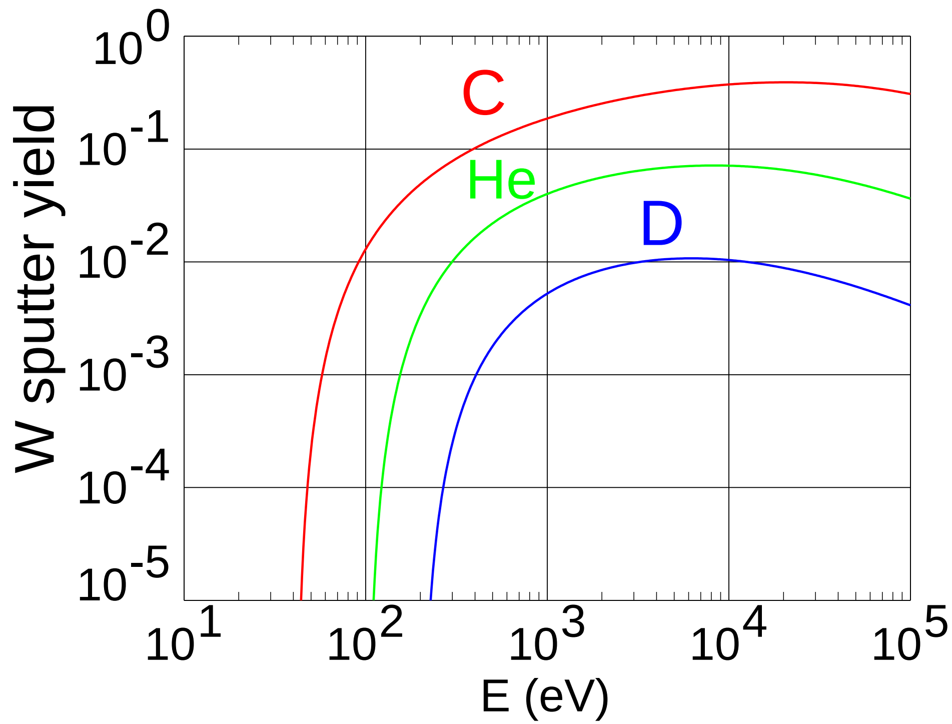
- for thermal plasma ions W erosion is dominated by carbon sputtering
- strong function of temperature for T < 10 eV

- deuterium sputtering is only important for CX-neutrals or fast ions from NBI

versus plasma temperature
($E = 2\,k_BT + 3\,Z\,k_BT$)

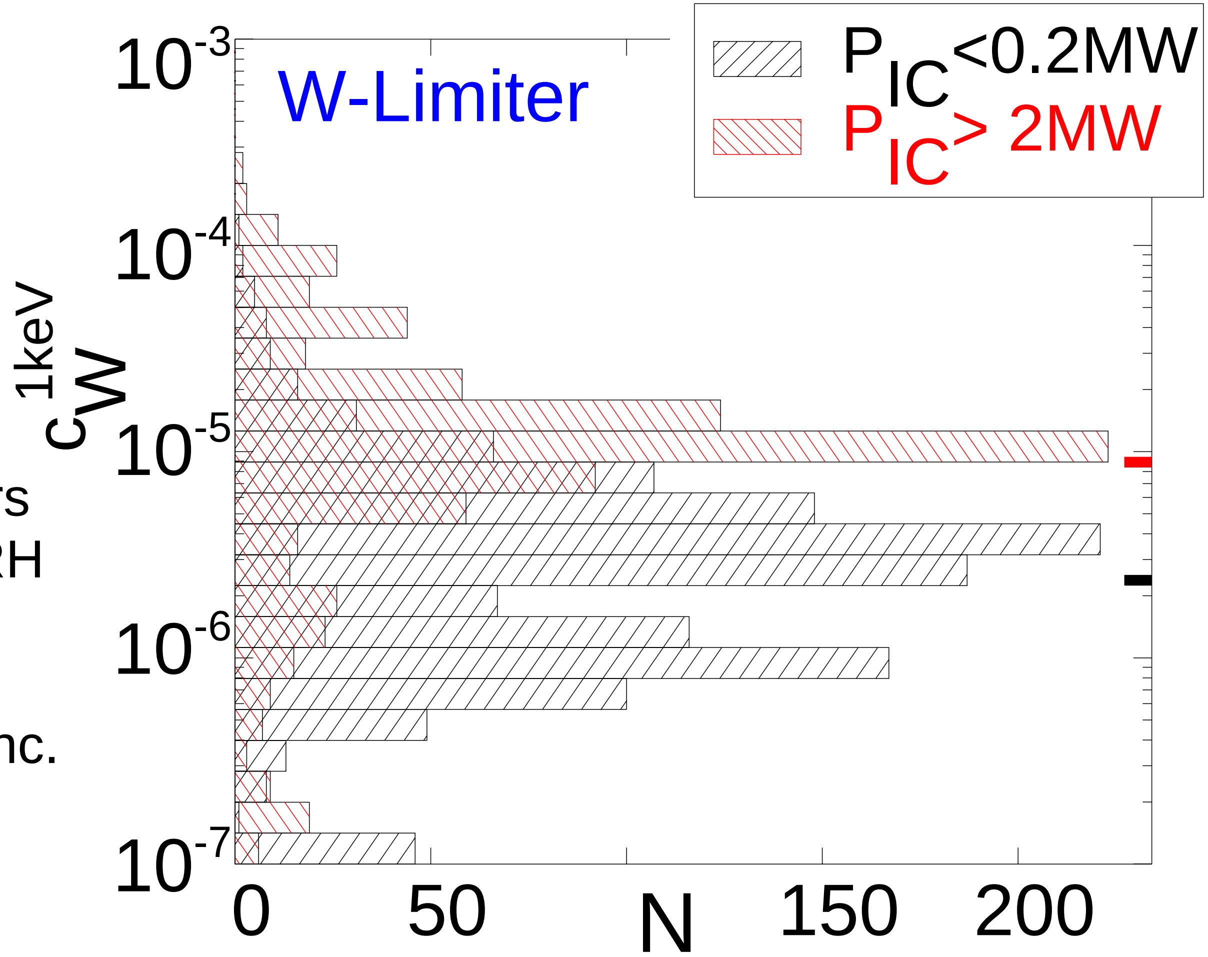


versus particle energy



W concentration with addition of low-field side limiters

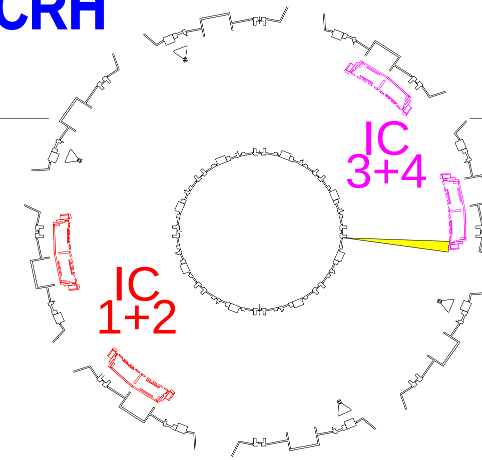
- wide distribution of concentrations
  transport
    H-mode barrier: ELM frequency
    plasma centre: low anomalous
      transport → W accumulation
  source
    hot/colde plasma edge



- increase of c_W with new W-limiters
  only visible for discharges with ICRH
  ⇒ strong increase of W source at
    limiters
  (similar ICRF effect seen for Mo conc.
  on Alcator C-mod)

with ICRF: mean conc. = 1E-5

Strong increase of tungsten influx at ICRH limiters with ICRH



instantaneous (<1ms) and localized increase/decrease of influx at limiters of active antennas

predominant fraction of limiter erosion (averaged over all lines-of-sight) due to ICRH

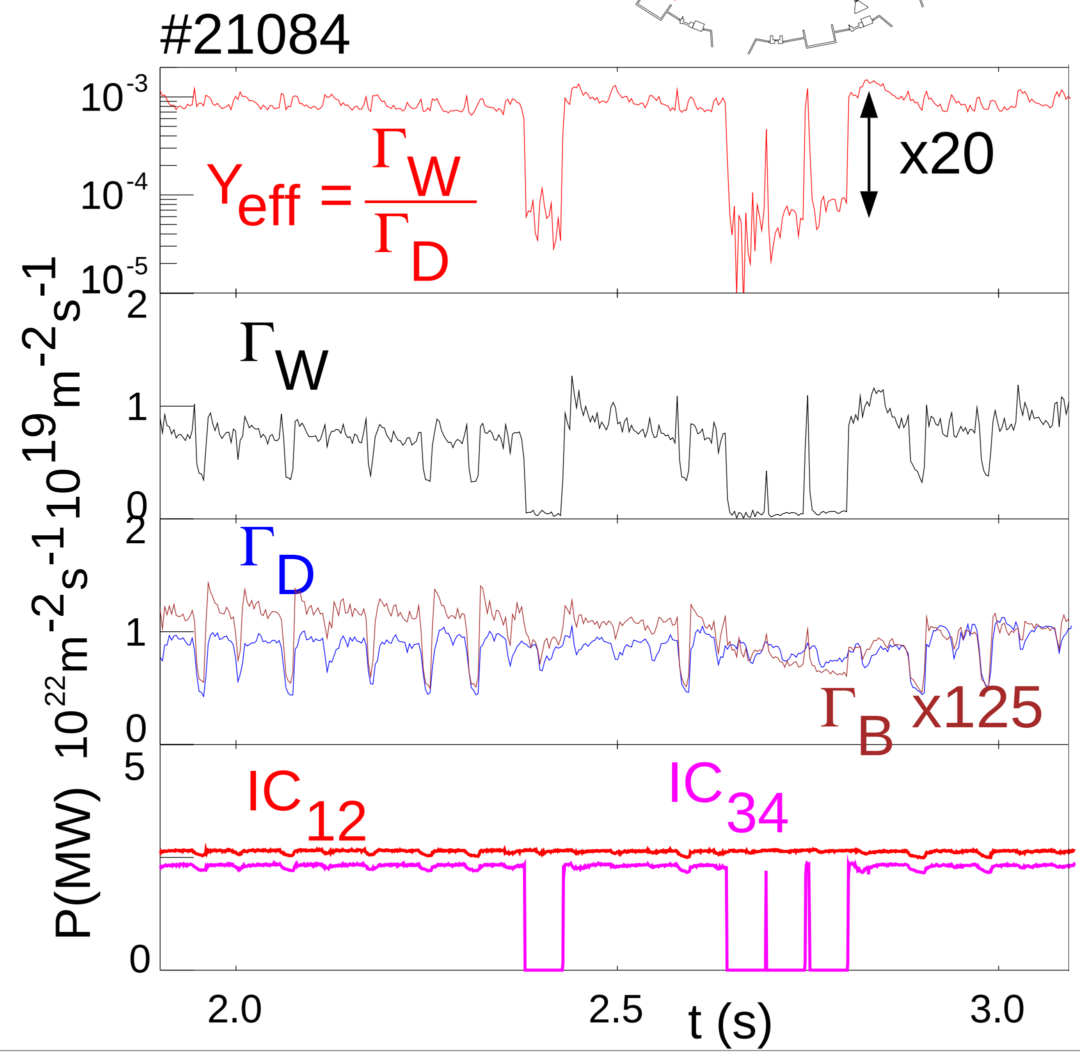
$$\frac{\Gamma_W^{on} - \Gamma_W^{off}}{\Gamma_W^{on}} = (60\text{-}95)\%$$

for heating power fraction (10-60)%

interpretation

sheath rectified electric fields

(no fast ion effect)



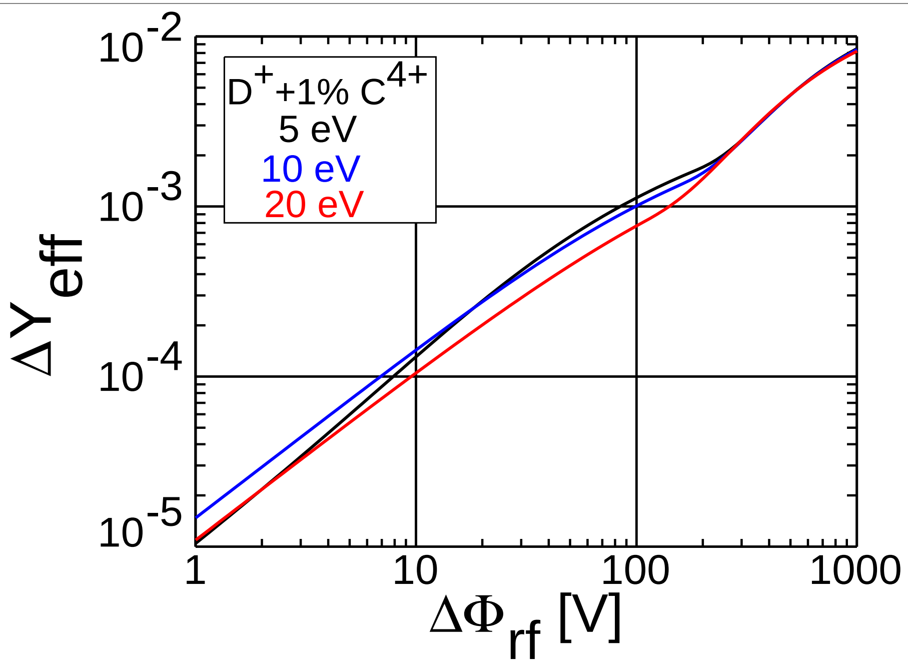
no effect
for boron influx!

Increase of sheath potential with ICRH can be estimated from increase of effective sputter yield

energy dependence of sputter yield

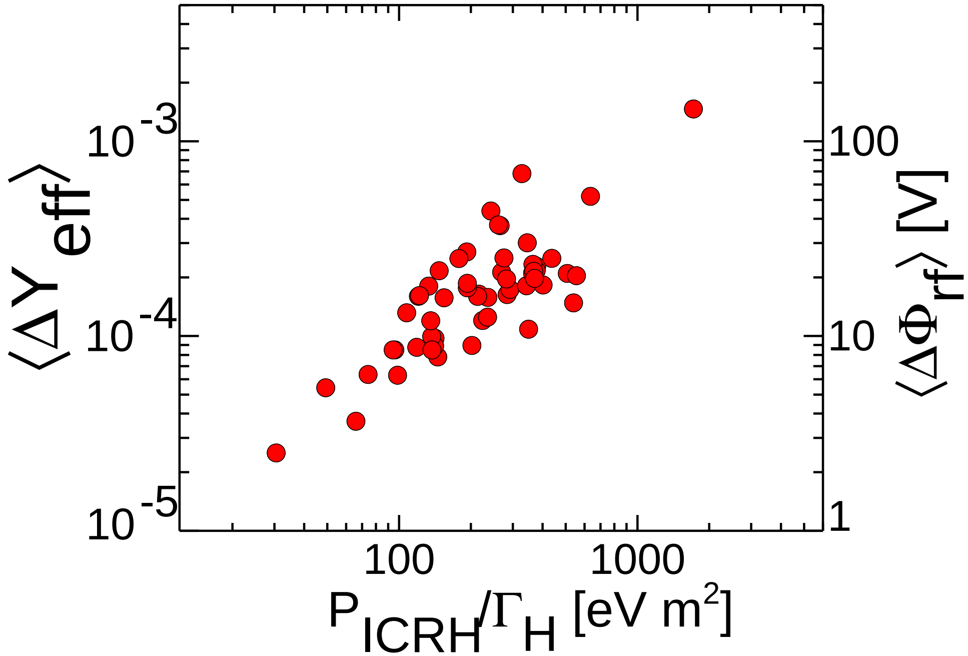
- increase of sheath potential by $\Delta\Phi_{rf}$ causes extra acceleration of impurity ions and increase of eff. yield

$$\Delta Y_{eff} \approx 10^{-5} \times \Delta\Phi_{rf}\,[V]$$

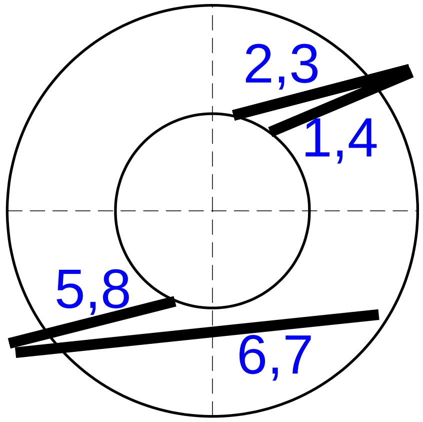


measured increase of yield gives:

- approximate range:
  1V < ΔΦ_rf < 100V
- increase with P_ICRH
- ΔΦ_rf low for high recycling cold edge conditions

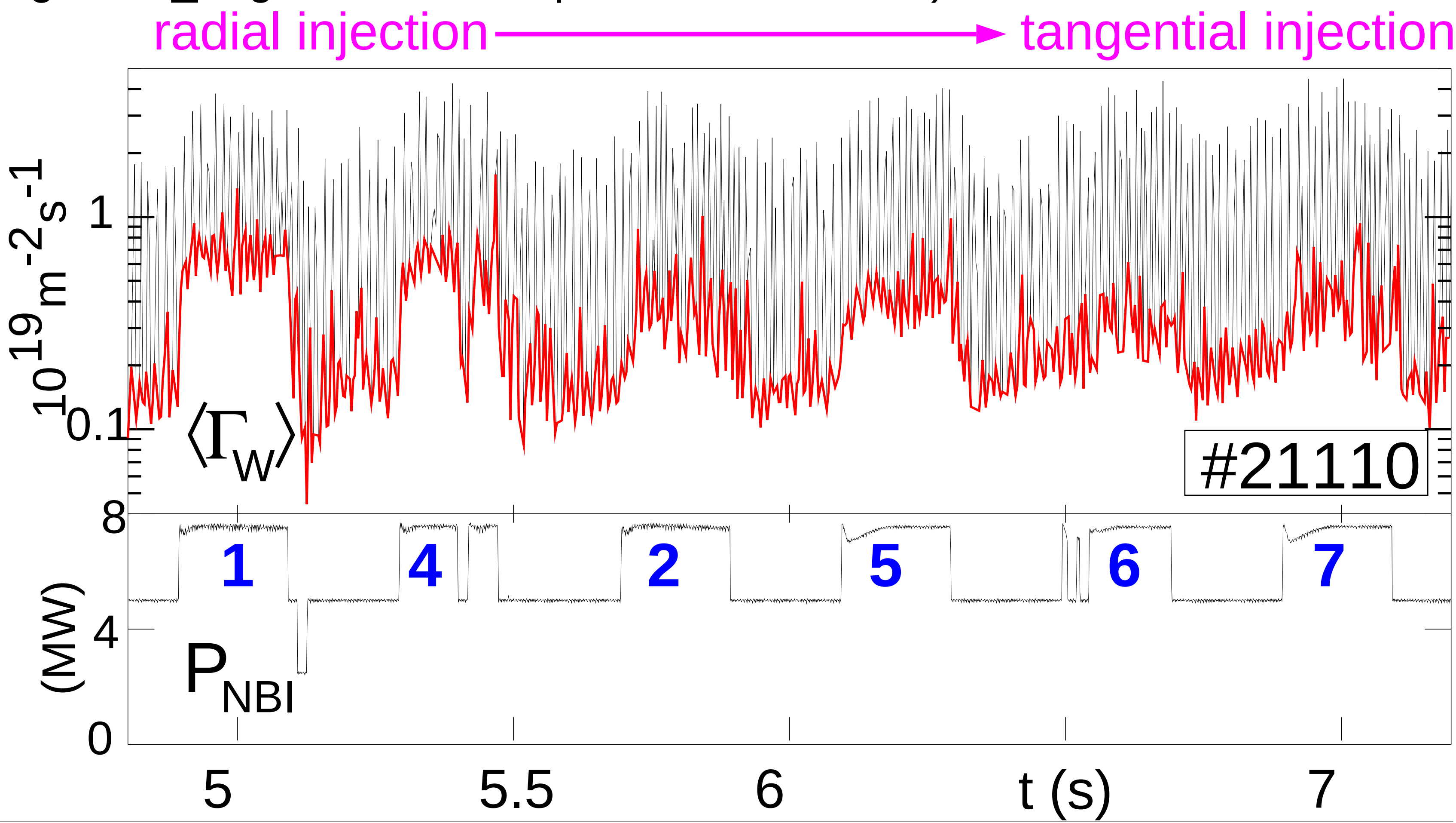


Sputtering by fast D ions from NBI:
Scan of NBI sources with different injection angle



Loss of fast ions from NBI heating
- depends on the injection angle (radial vs tangential)
- leads to different W influx from limiter

H-mode with 2 beams + scan of other beams
(idea: small change of T_edge to measure pure fast ion effect)



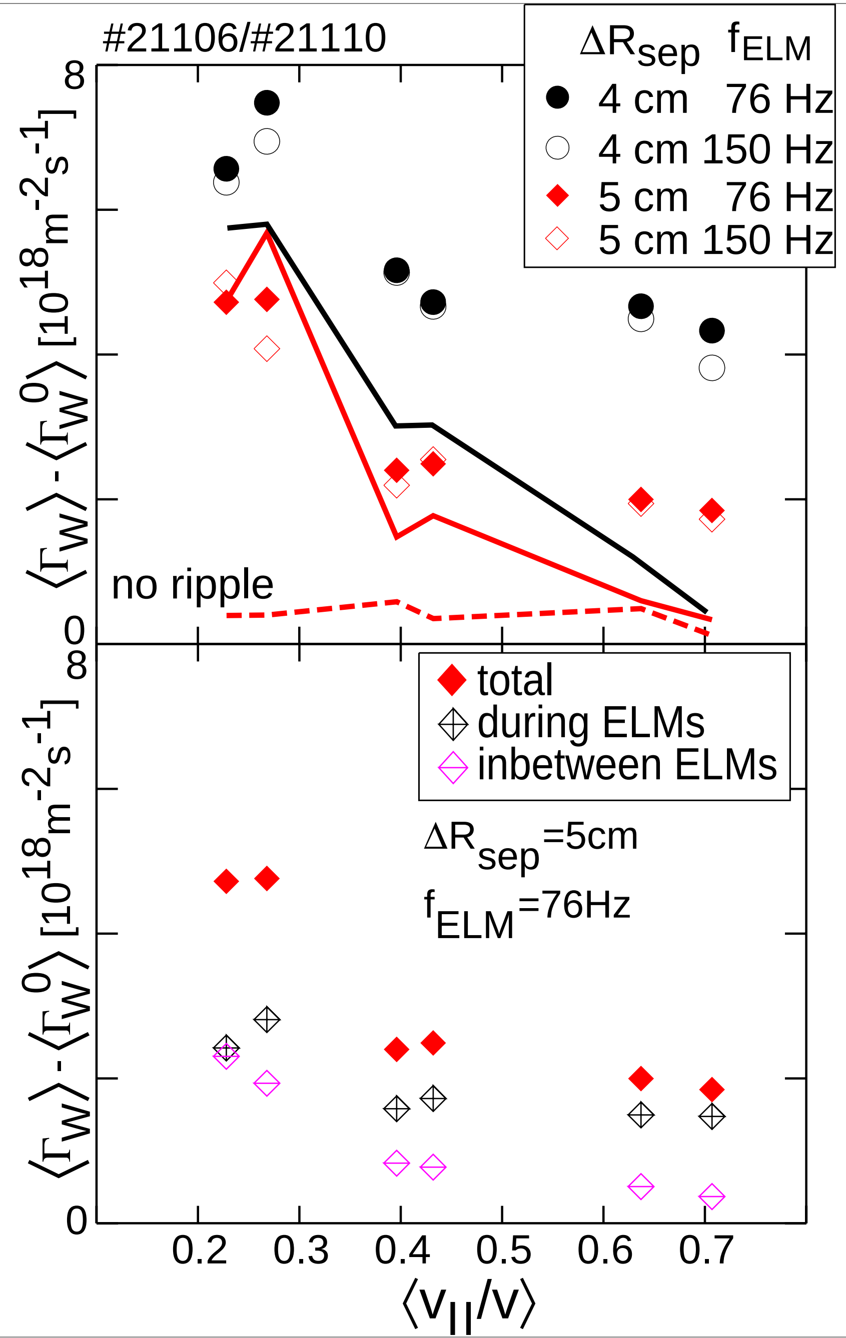
Experiment vs Monte Carlo Code

- 4 scans: ELM frequency = 76Hz/150Hz
  distance separatrix-limiter= 4/5 cm
- mean change of W influx for each beam

Monte Carlo Code
- start positions of fast NBI ions
- orbits of gyro centre of fast ions
- slowing down and transport of fast ions by collisions and magn. field ripple

→ ripple transport is important loss mechanism
→ calculated change has stronger dependence on average pitch angle of source

ELMs:
- measured pitch angle dependence different for ELM on/off phases (can be estimated for low ELM frequency)
- mean effect identical for low/high f_ELM
- ELM induced losses also observed on fast ion detector



Effect of type-I ELMs on the W erosion at the limiters

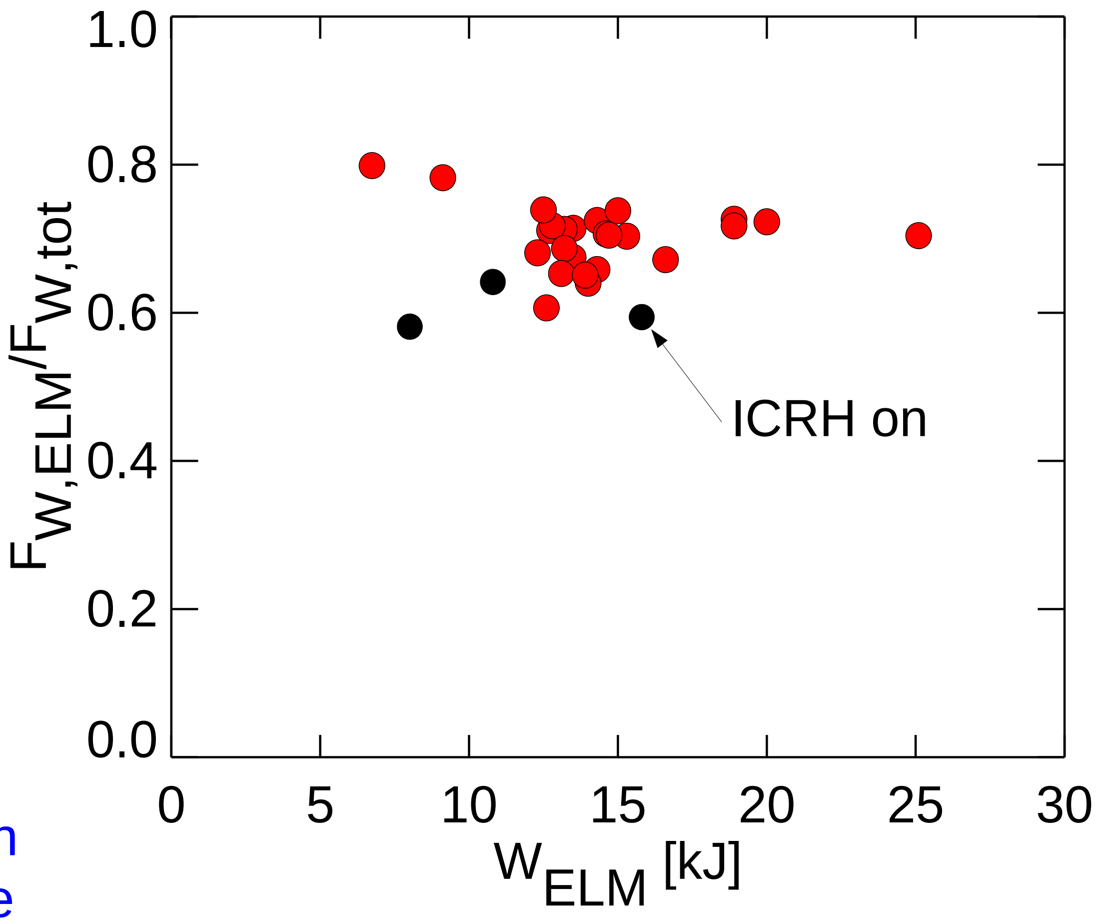
253µs time resolution on one line-of-sight
(so far only a few discharges)

during ELM drastic increase of W influx by more than a factor of 10 (lower increase for B and C)

For a data set with:
6.7 kJ ≤ W_ELM ≤ 25kJ
175 Hz ≥ f_ELM ≤ 46 Hz

- contribution of ELMs to the local W influx constant: ≈(70±10)% (many small ELMs lead to same influx as less frequent larger ELMs)

- increase of W influx due to rise of mean energy of ions hitting the limiter (increase of effective yield)



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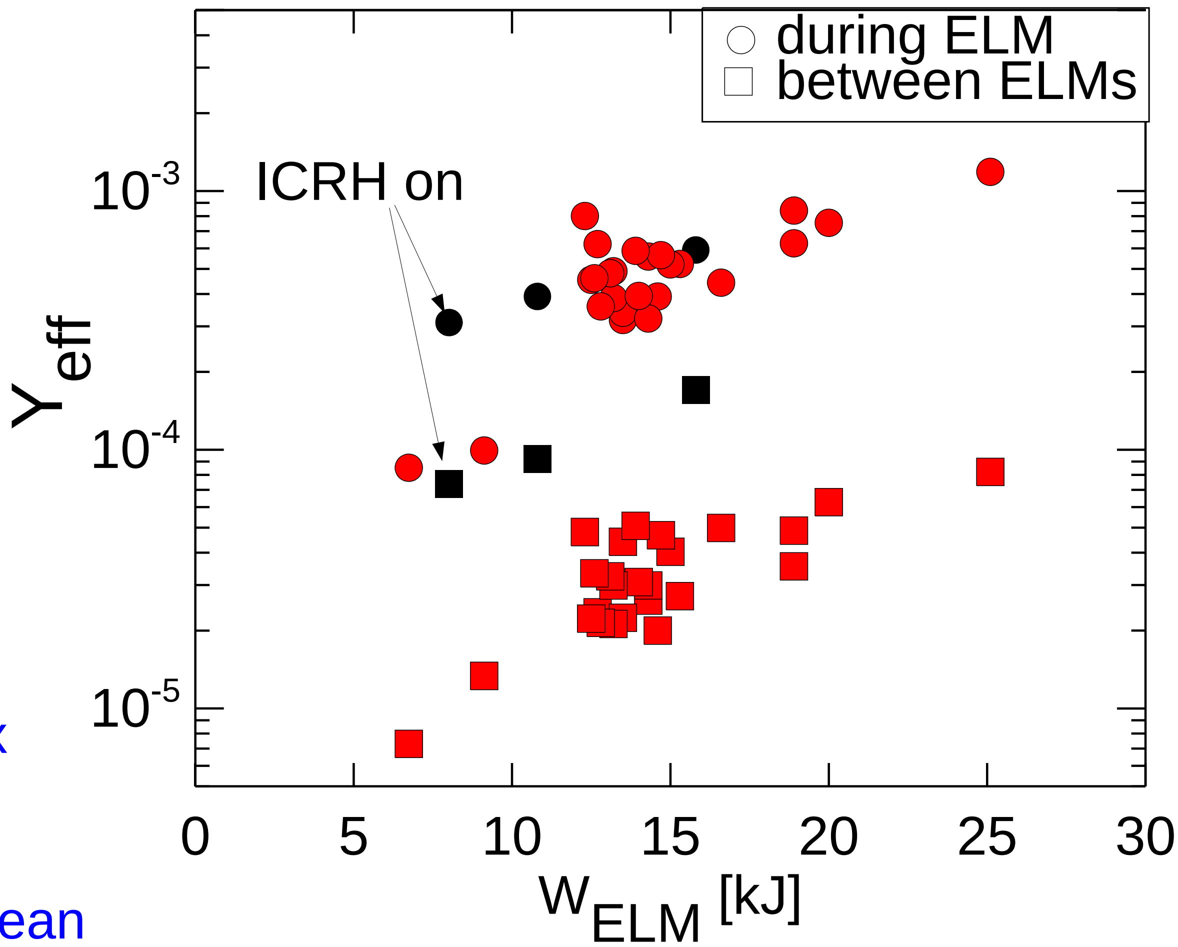

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Implications of W-PFC on Helium Recycling

- observations at ASDEX Upgrade
- related laboratory experiments on He retention/release

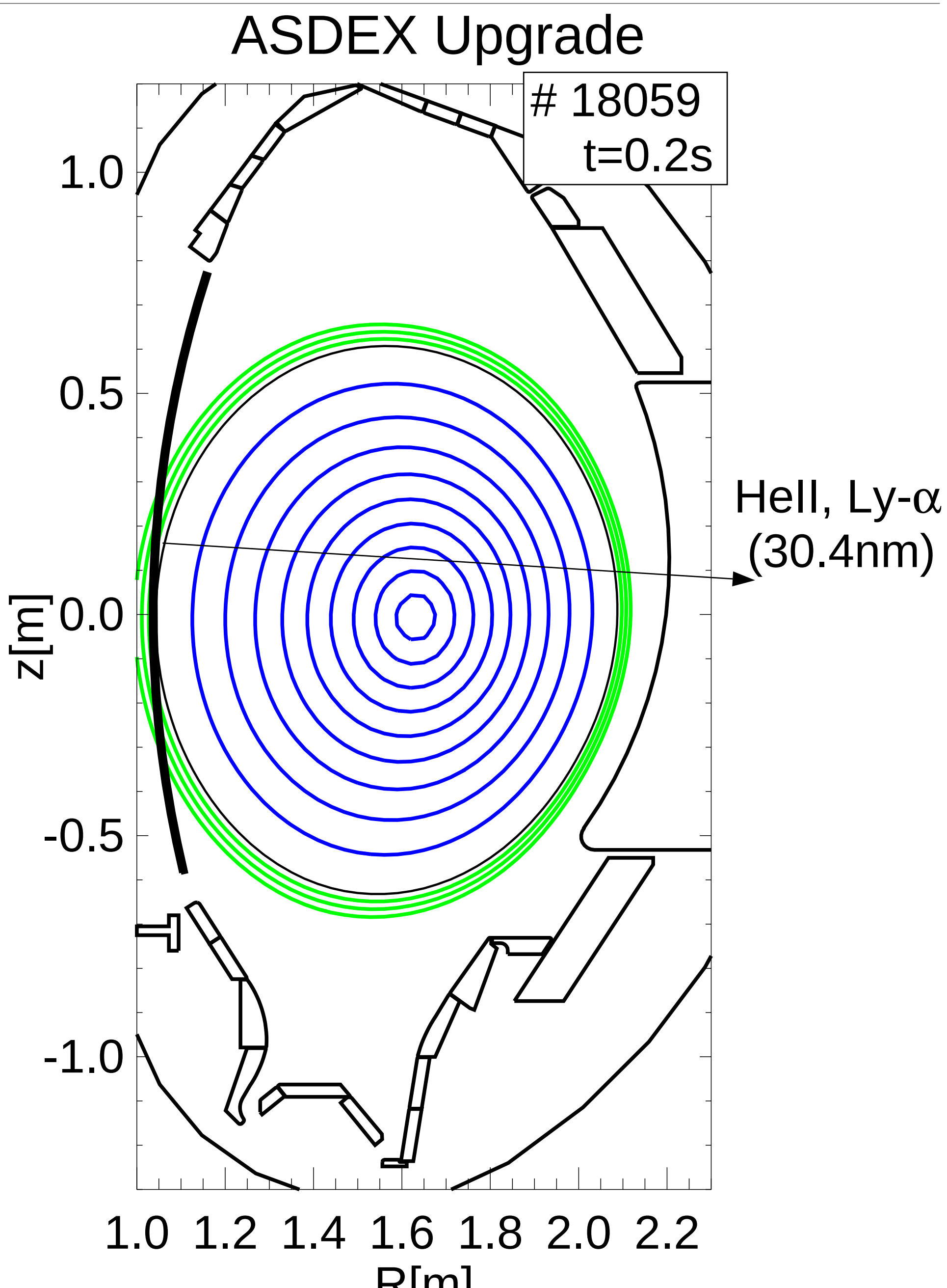
Implications of Tungsten on Helium Gas Recycling

Helium Glow Discharge (HeGD)

- 15 min before plasma operation
- 5 min after each discharge
- U ≈ 400V

Helium release from inner heatshield (HS) during ramp-up (limiter plasma)

- ≈10 x lower for graphite than for tungsten
- ≈100 x lower for boronized tungsten HS



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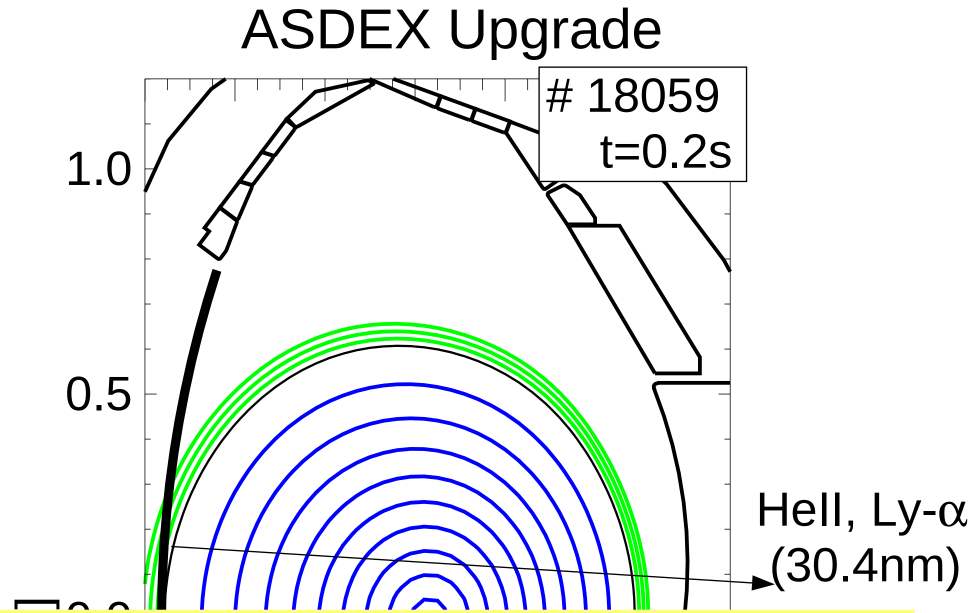

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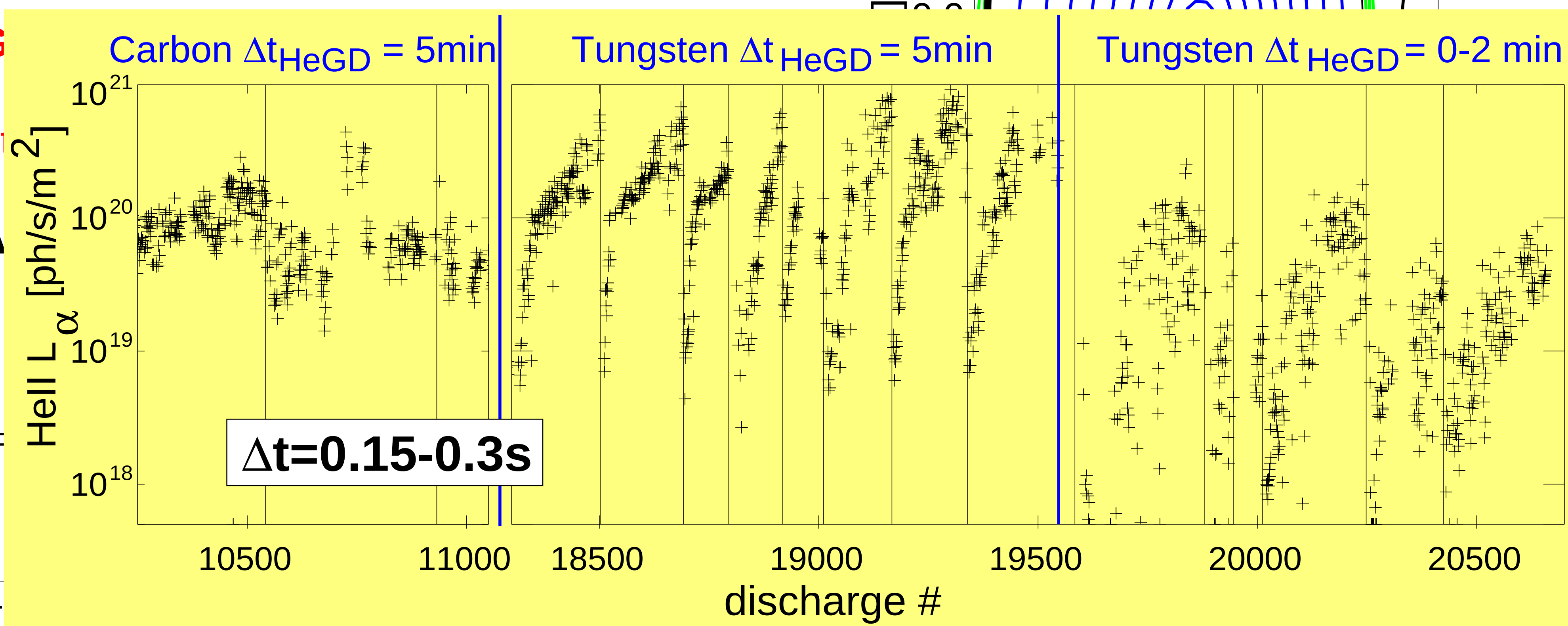

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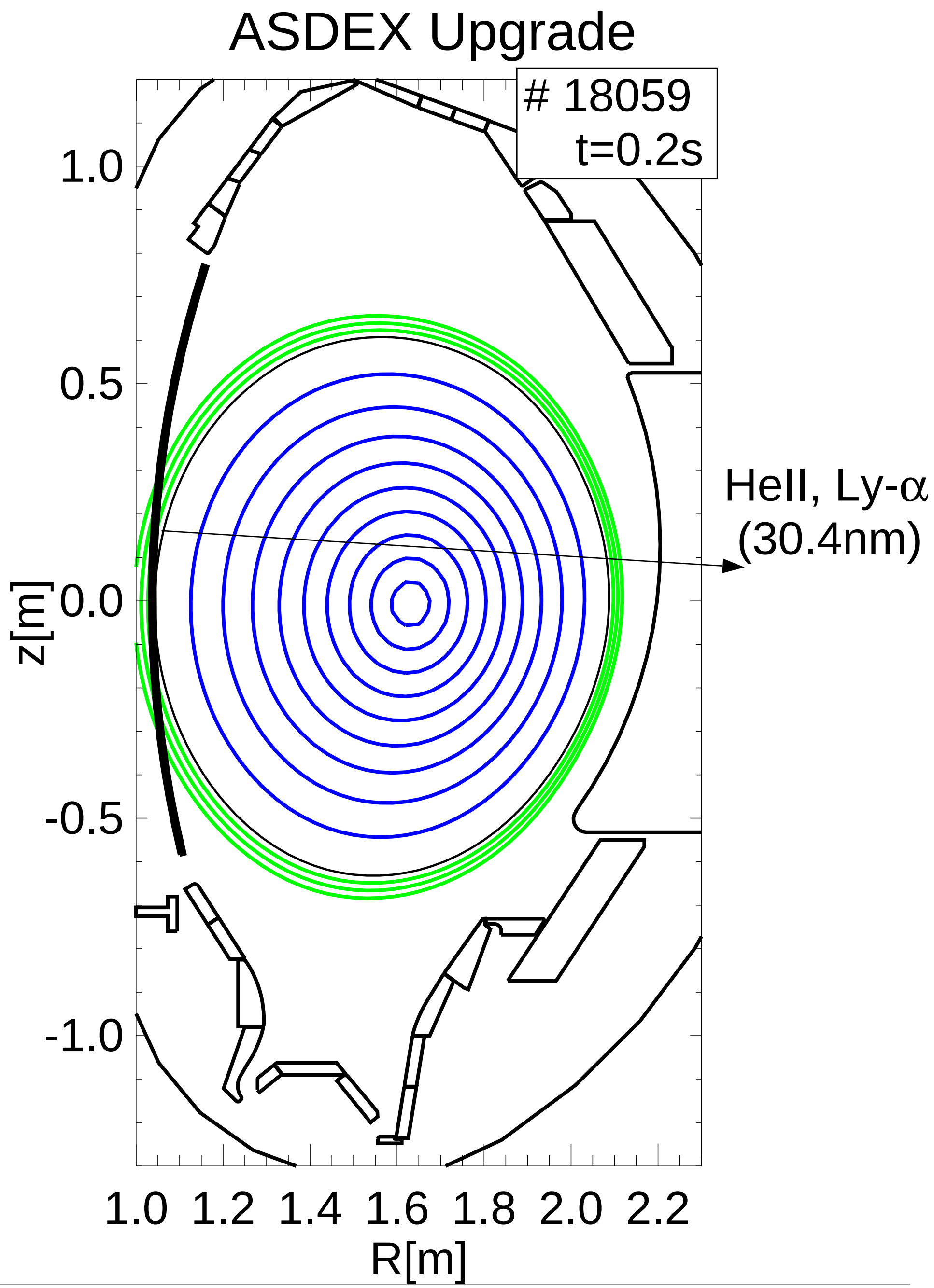
Gas consumption during ramp-up
- ≈100 x larger for graphite than for tungsten

Assumption
- W retains more He during HeGD leading to a larger He-source

⇒ **test in laboratory experiments**



Laboratory Experiment: ECR plasmas to mimic implantation during HeGD and removal during plasma operation

usage of ^{3}He isotope

- sensitive detection by nuclear reaction analysis

Samples

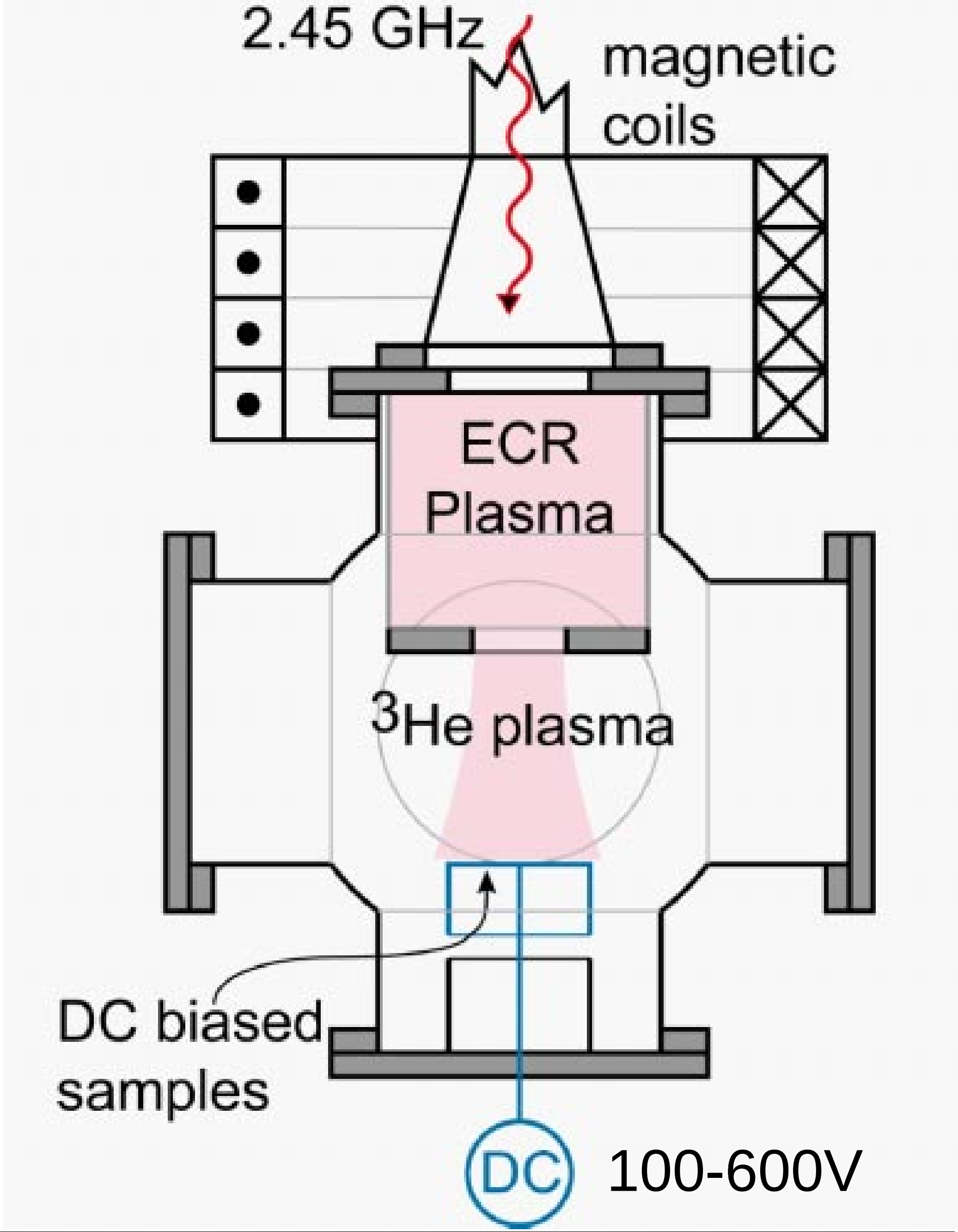
- PVD-W, solid W
- graphite: fine grain, pyrolythic ...

Implantation

- ^{3}He ECR plasma with DC bias of 200 and 600 V

Removal

- thermally
  thermal desorption starts at 400K independent of sample
- plasma load
  H and ^{4}He ECR plasma with DC bias of 100V



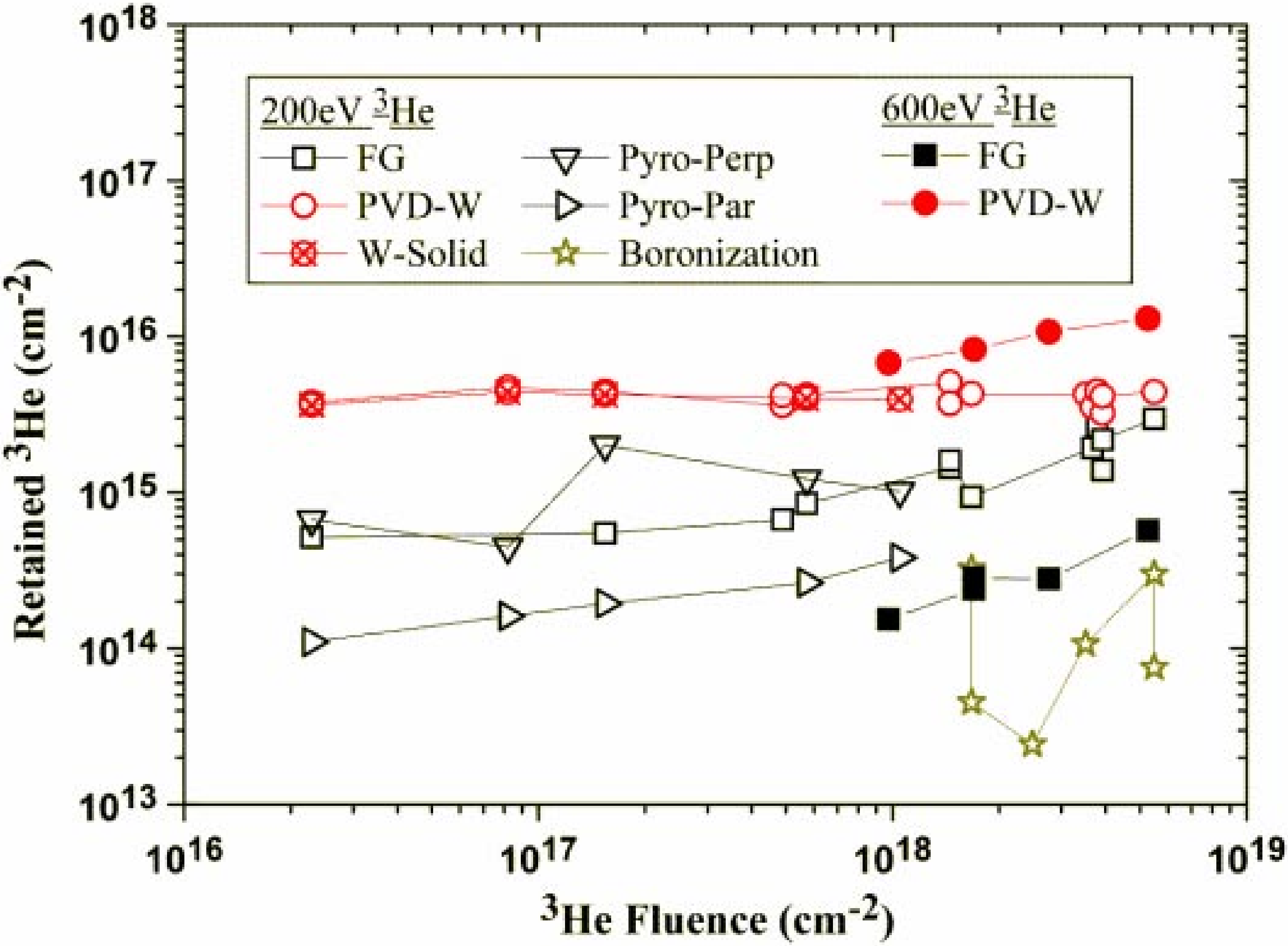
Higher He-Retention in Tungsten than in Graphite

- early saturation of retained He reflects low penetration depth of He

TRIDYN:
in W: ≈ 3.4±1 nm
in C: ≈ 2.6±1 nm

- higher He-retention in W
  200V: ≈ 10x
  600V: up to 100x

- with increasing voltage
  W: retention ↑
  C: retention ↓
  (erosion yield of C 6x erosion yield of W at 600V)



Similar Fraction of retained He released

release probability

^{4}He plasma

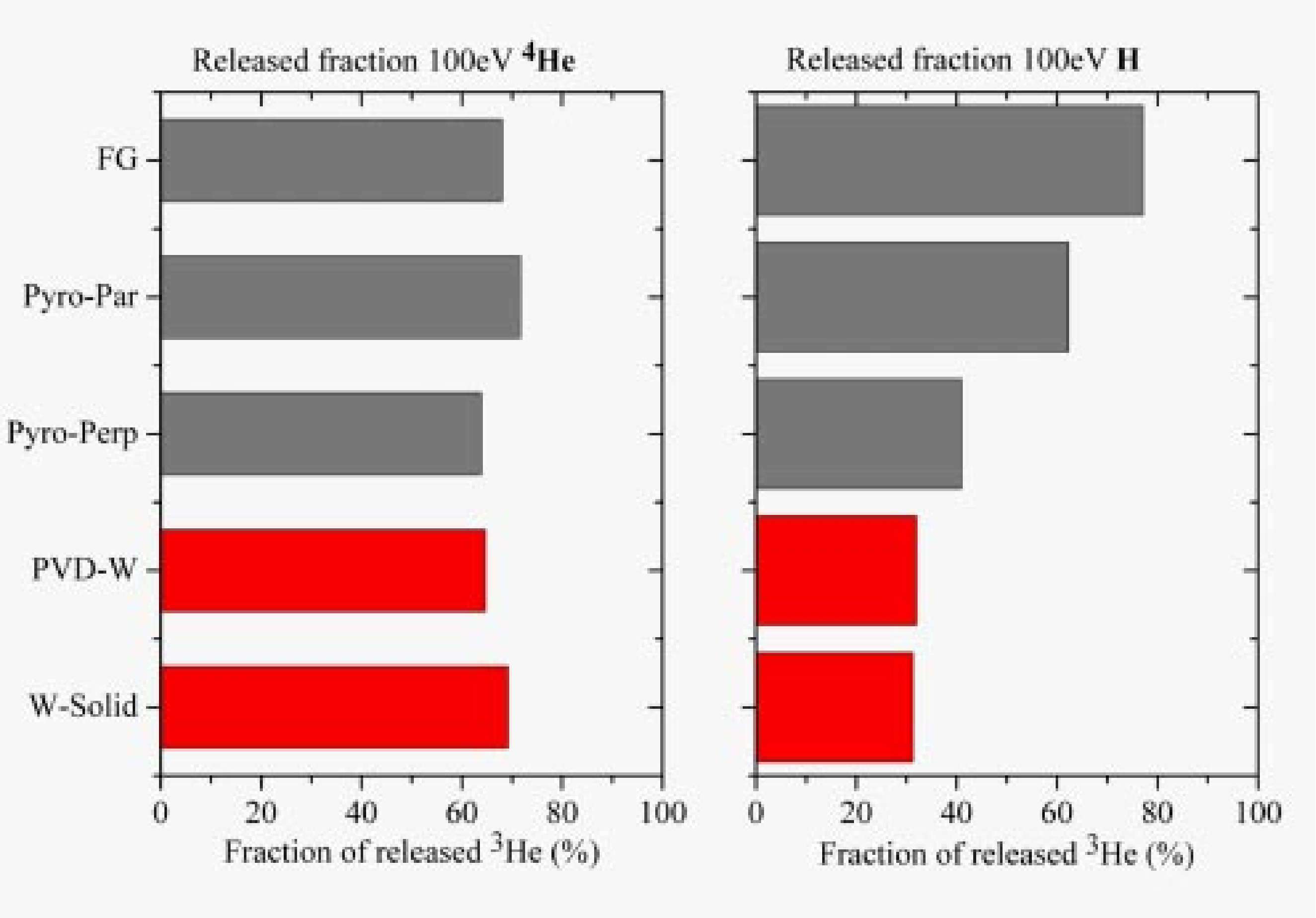
- C and W very similar in He plasmas (penetration depth of ^{4}He about 60-70% of the penetration depth of ^{3}He)

H plasma

- roughly 2x higher in C (additional chemical erosion of C)

in total

- the main difference is the higher He retention in W leading to higher He release



For a device with T_{wall} > 400K: He recycling for C- and W-PFC identical !

Conclusion

Carbon concentrations are slowly decaying with increasing W coverage

- present values can be explained with a net divertor source leaking into the main chamber, where C recycles many times

W erosion at the low field side limiters in ASDEX Upgrade

- during diverted discharges only detectable when ICRH or NBI is used
- fast D ion sputtering is important contribution for plasmas wo ICRH
  - modeling results agree well with experiment
  - small contribution in ITER due to ρ^*-scaling (for reasonable ripple!)
- impurity sputtering is strongly increased with ICRH heating and yields the dominant contribution (rectified sheath potential!)
  - optimization of ICRH antenna (Faraday screen)
- ELMs lead to a strong increase of the W erosion due to a rise of the mean energy of the impinging ions

Helium retention in W is higher than in C

- W is quickly saturated and releases He simlar to C
- thermal release starts at 400K

Next Campaign ASDEX Upgrade is a W-device

- 200µm VPS-coated tiles for divertor strike point area
- need to control divertor radiation by puffed impurities