Max-Planck-Institut für Plasmaphysik

IPP

Tungsten Erosion by Arcs in ASDEX Upgrade

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- Motivation
- Post mortem tile analysis
- Real time observations
- Dust production by arcing

Motivation

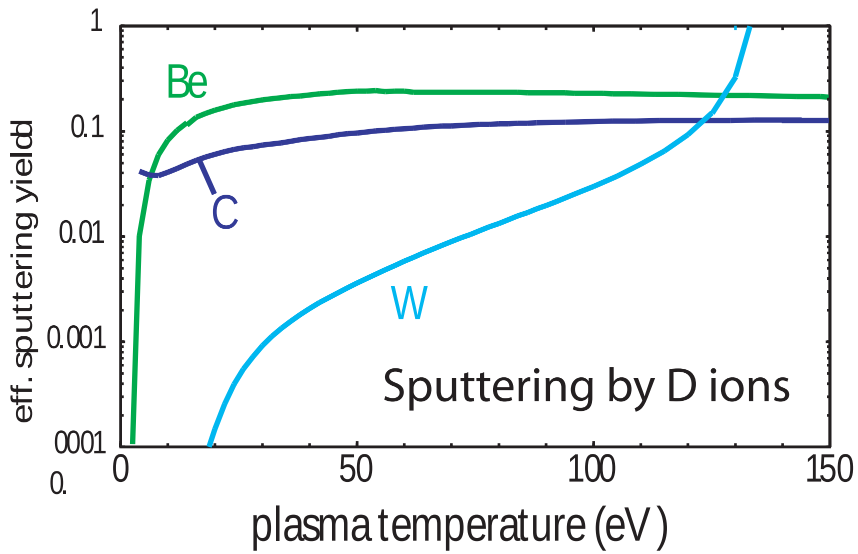
Sputtering versus arcing

1980: sputtering and arcing discussed as erosion processes (*McCracken , J.Nucl.Mat.,93&94, 1980*)
change carbon PFCs : physical and chemical sputtering dominates
few investigations on arcing, arcs only during transient phases
2010: metal wall in divertor devices, H-mode with ELMs.

ASDEX-Upgrade: tungsten PFCs
divertor, radiation cooling: Te ~ 10 eV
sputtering only by impurities
erosion by arcs depends on material: no threshold
arc traces observed for C and W PFCs

	T_{melt} C	λ W/mK	E_r µg/C	E_r at/C
C	3650	75	13.5	$68.0*10^{16}$
W	3380	130	27.1	$8.8*10^{16}$

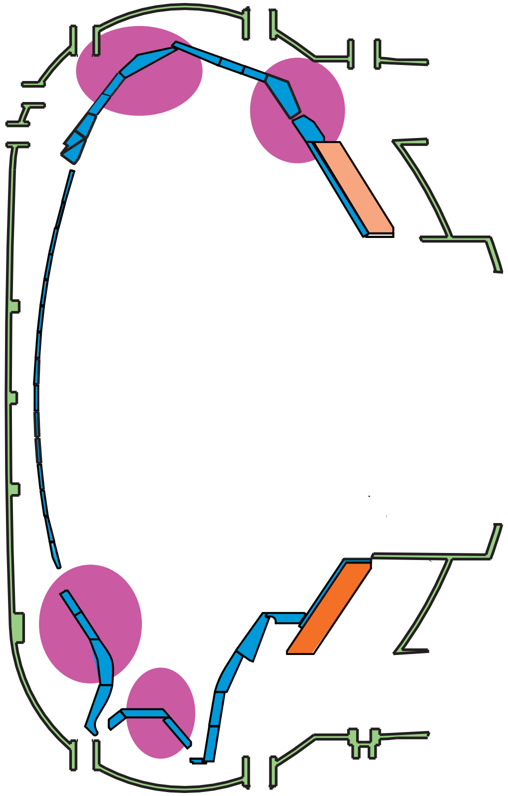
erosion by arcing quite similar



Is erosion by arcing negligible in future fusion devices ?

Regions effected by arcing

arc traces are inhomogenious



Visual inspection after a campaign yields arc traces at many locations

three kinds: irregular movement: Glow discharge cleaning

accidentical arcs: between structures in B direction

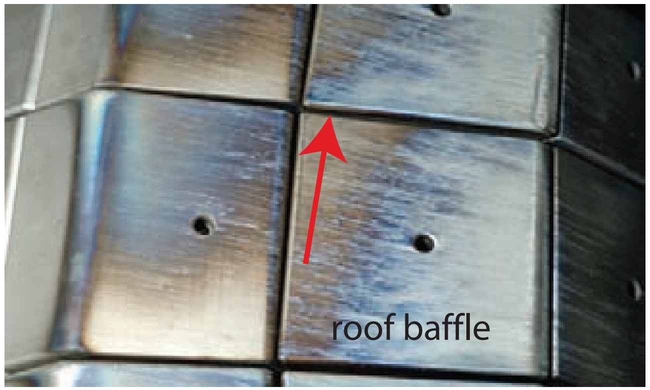
arcs on PFCs : this talk

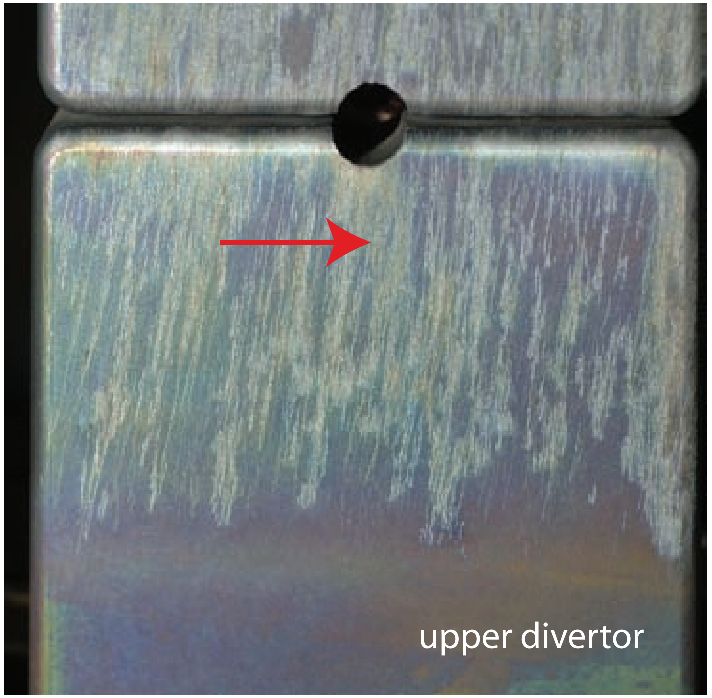
uni-polar arcs: plasma works as anode

retro-grade movement perpendicular B

observed at some locations

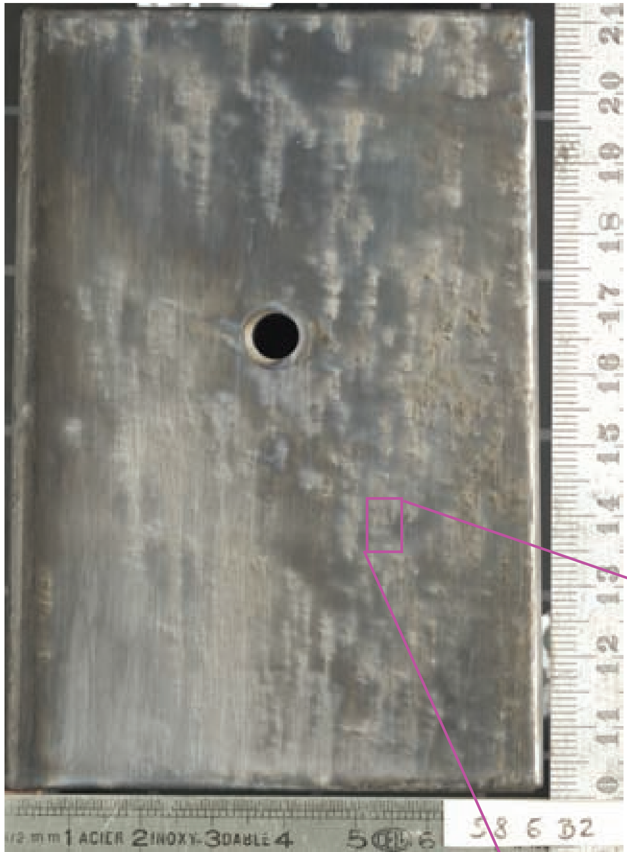
number of arcs changes on short scales





Post mortem analysis

Scanback camera



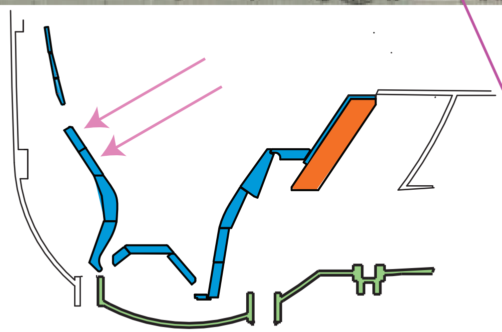
~ 4000 tiles are mounted as PFCs at AUG

Strategy: select typical tiles by eye
scan for optical analysis
depth profiles of typical regions
SEM on interessting locations

96 tiles selected, removed and scanned

high spatial resolution needed: 6 µm

focus on inner divertor baffle: strongly demaged region
tile with W coating, additional TiO_2 layer
fast camera observation



picture of isolated tile
different colors, layers ?
cut out of picture
typical arc traces
splitting of traces allows to determine direction
flawy structures at start of some traces: starting signature

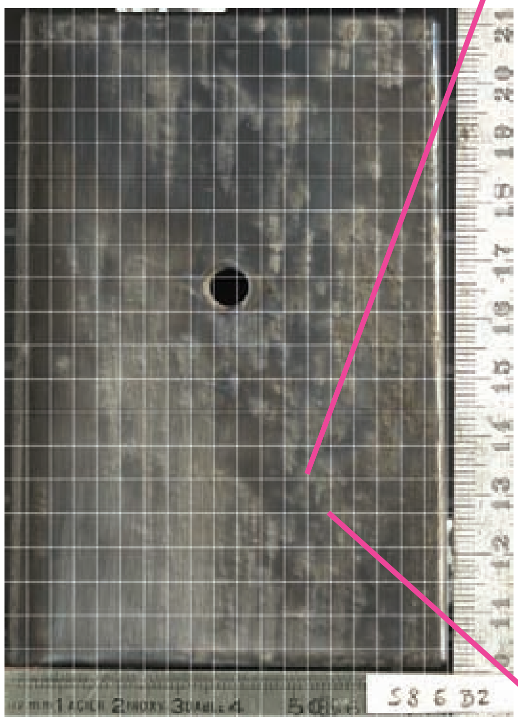
Post mortem analysis

Identification of traces

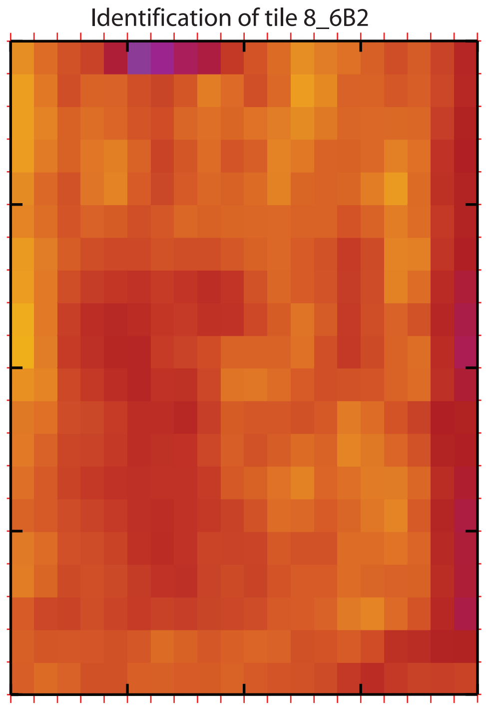
automatic trace identification needed to get comparable results:

- divide scan to 20 * 20
- identification of arcs by contrast/intensity /direction

reliable criterion > independent from observer



arcs only as long tracs
5.3 % of surface eroded
almost homogenous erosion on this tile
lower limit for total erosion (pits ..)
depth of traces needed



ASDEX Upgrade

Post mortem analysis

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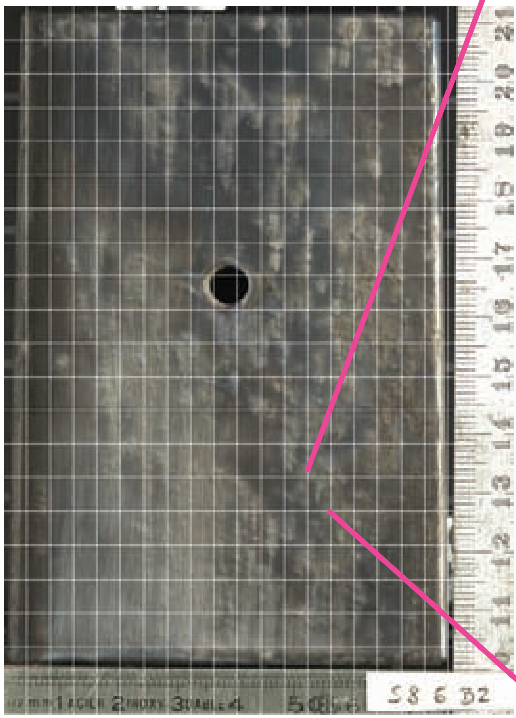
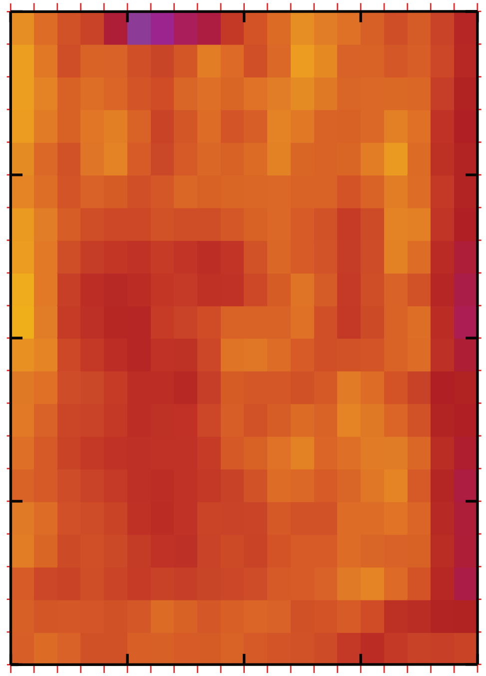
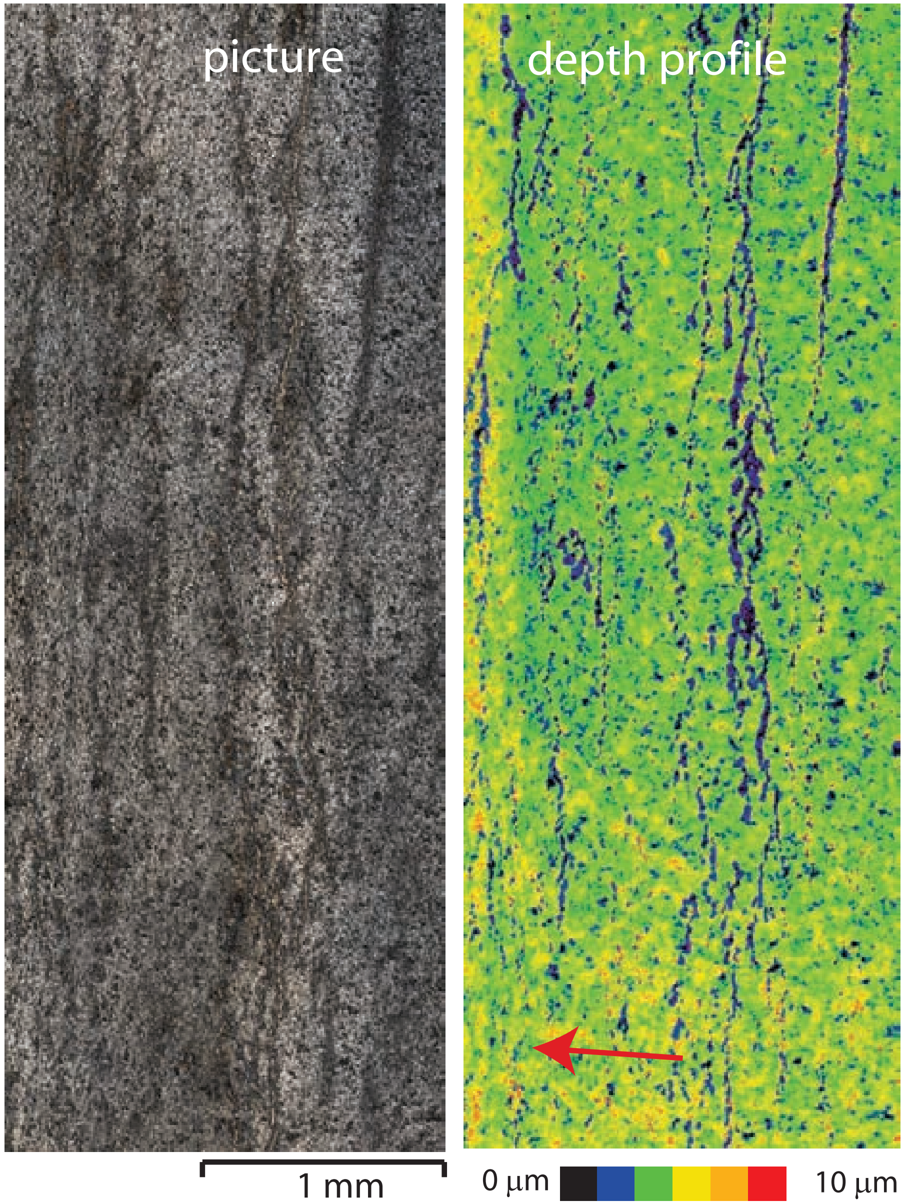


Identification of tile 8_6B2



Post Mortem Investigations

confocal laser scanning microscope



Tiles analyzed by confocal scanning microscope
with integrated blue laser profilometer
  spatial resolution: 0.8 µm
  depth resolution : 10 nm
scan area 1700 * 1700 µm

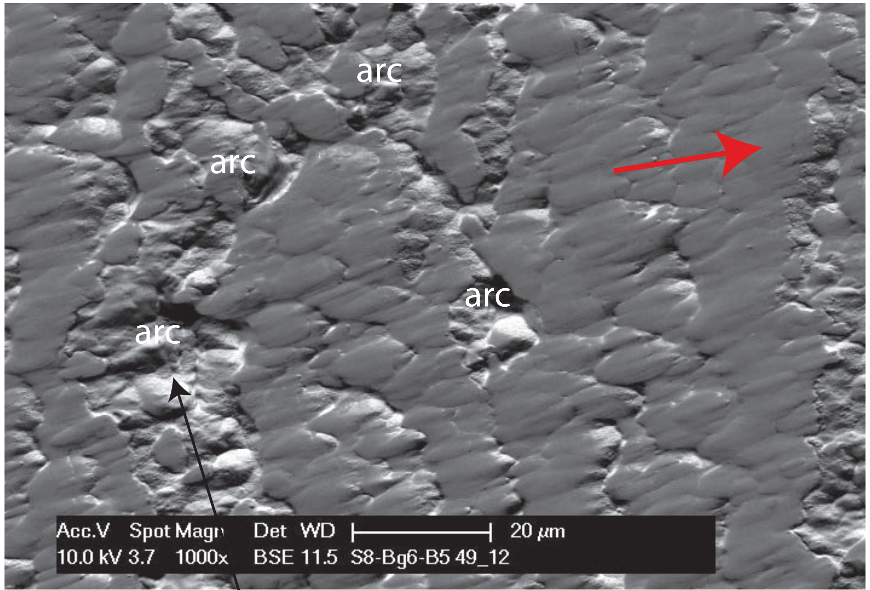
only parts of tiles scanned
  picture with full depth of sharpness
  2-d depth profile

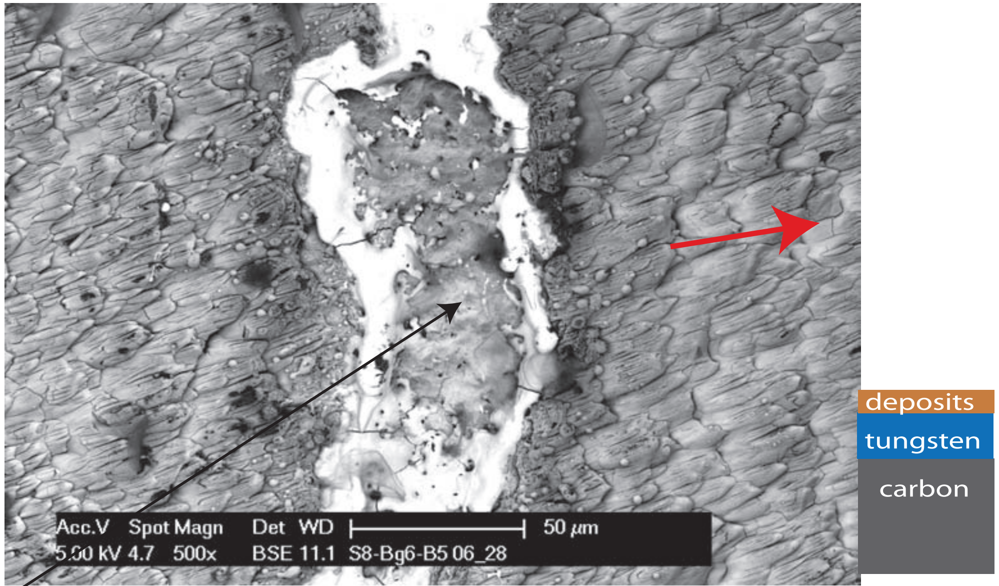
two kinds of arc traces
- long structures : Type 2
  50 µm * 5 mm , > 5 µm depth
  orientated perpendicular B
- dips : Type 1
  10 µm *10 µm, 5 µm depth

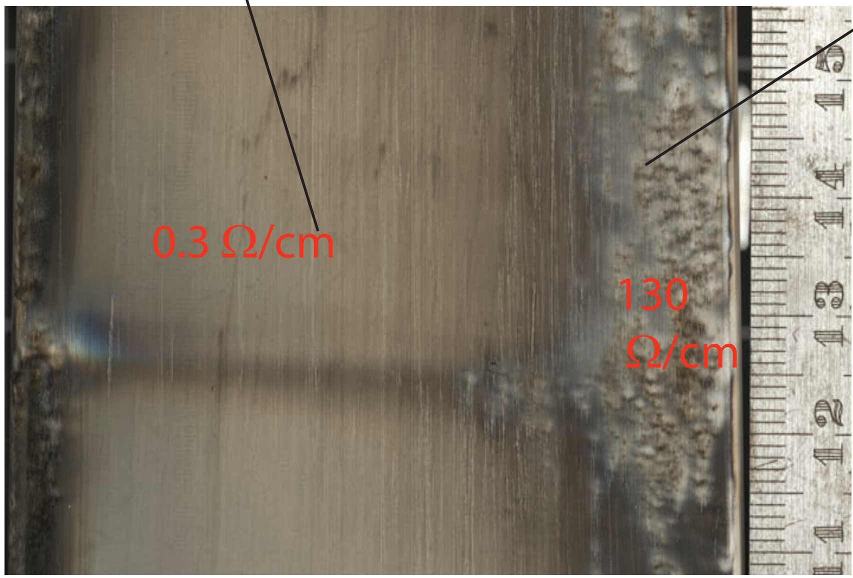
affected area obtained
  microscope 5.8 %
  optical 5.3 % of total surface

Post mortem analysis

SEM measurements







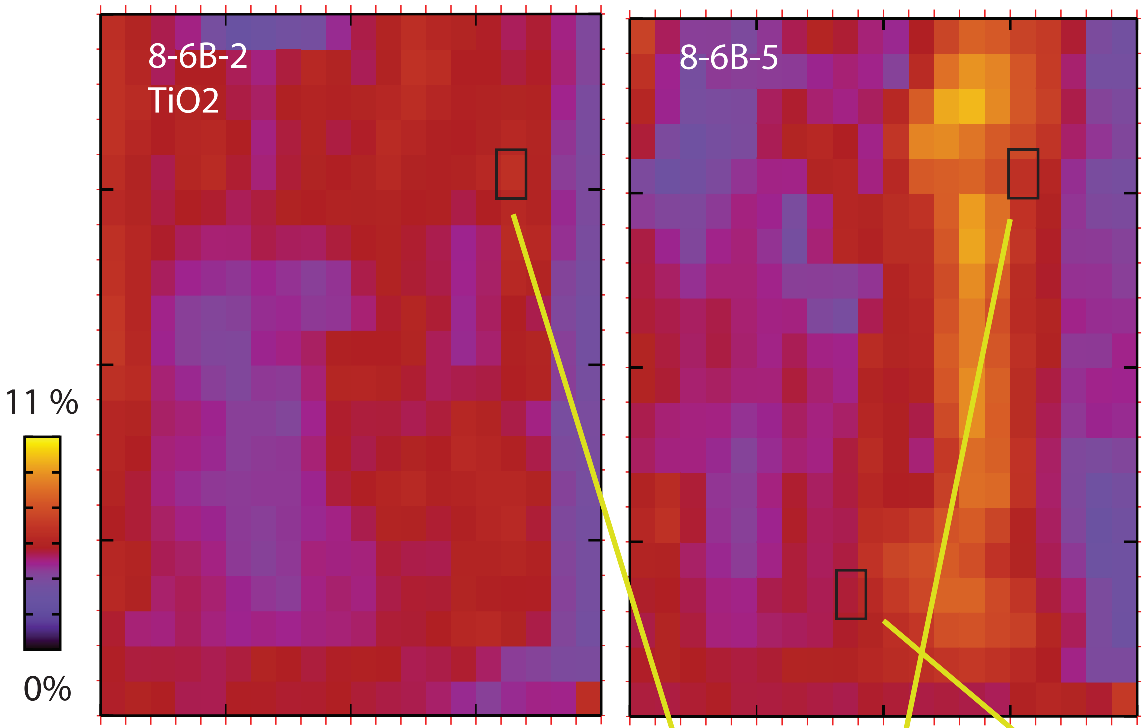
Detailed analysis of traces

optical observed arc w/o significant erosion
- region of low surface resistivity

optical observed arc with erosion
- region of higher surface resistivity
- carbon substrate
- molten tungsten
- tungsten droplets

Post mortem analysis

erosion enhanced by isolating layer



surface		B2 TiO2	B5-1 pure	B5-2 pure
eroded fraction	%	4.71	3.28	
erosion	mg/cm^2	2.81	1.98	
fraction area		1.00	0.25	
fraction W		0.60	0.70	
total	g	13.54	2.79	0.00
physical sputtering	g	0.41	0.41	
divertor deposition	g	33.33	33.33	33.33
fraction	%	40.61	8.36	0.00

tiles from inner baffle region
- a: tungsten coated with TiO_2 on top
- b: tungsten coated

Optical evaluation of tile:
> fraction of arc affected surface looks similar

depth profiles from characteristic areas
> removed material
- TiO_2 tile: arc traces show erosion at whole tile
- pure tile : significant erosion only at deposited layers (25 %)

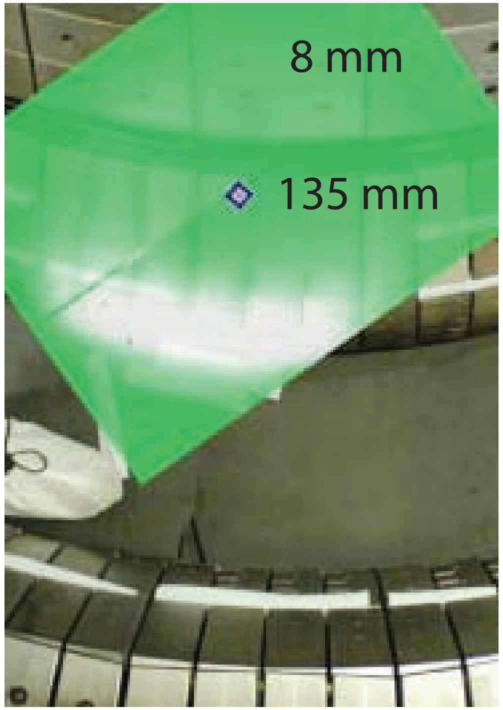
extrapolate to device
ion beam analysis < 2e17 at/cm^2

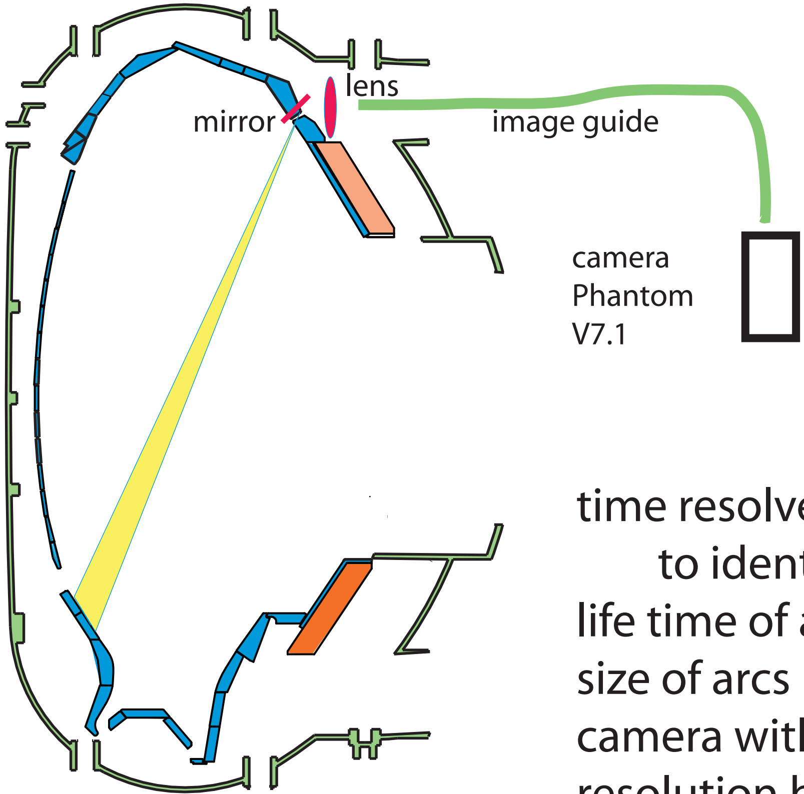
M.Mayer et al., Phys.Scr. **T138** (2009) 014039

Erosion by arcs domiates locally physical sputtering

Arcing events

fast camera observation





time resolved measurements needed
to identify arcing conditions
life time of arcs ~ 0.1 µs
size of arcs ~ 10 µm2
camera with high temporal and spatial resolution brings out arc

fast CMOS camera observing inner baffle
field of view 32*32 mm on tile 8_6B1
spatial resolution 150*150 µm2/pix
time resolution 26845 fps (256*256 pix)
exposition time 3 - 900 µs

#24739 - 25000 well conditioned
#25359 - 25450 after boronisation

Real time observation

many events due to droplets ?

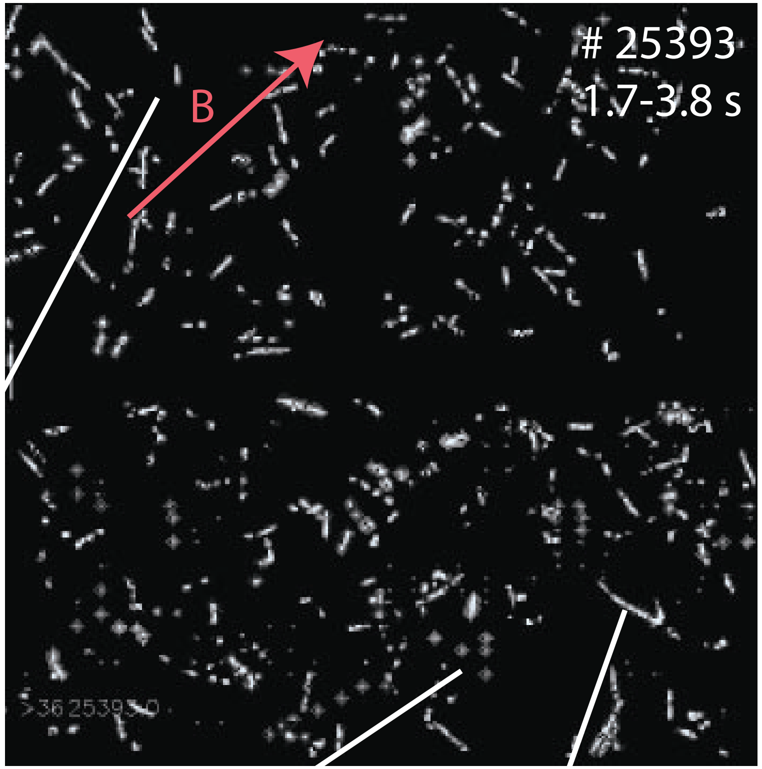
camera produces 20000 frames/shot
automatic data evaluation
local events identified and marked
quantity of events strongly varieties
from shot to shot

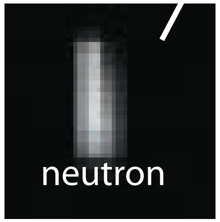
sum of all events during a discharge
H-mode discharge

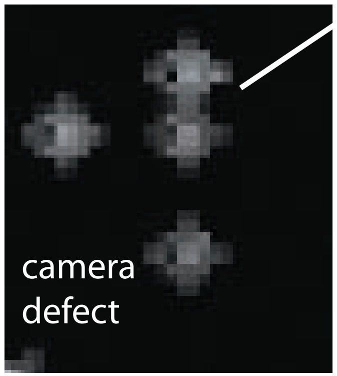
different kinds of events
- neutrons at image guide
- problems of camera
- arcs

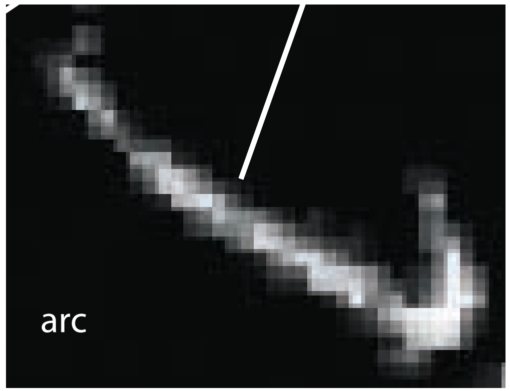
arc orientated perpendicular B
events more uniform

arcs produce droplets:
3500 K W-spheres
strong IR radiation









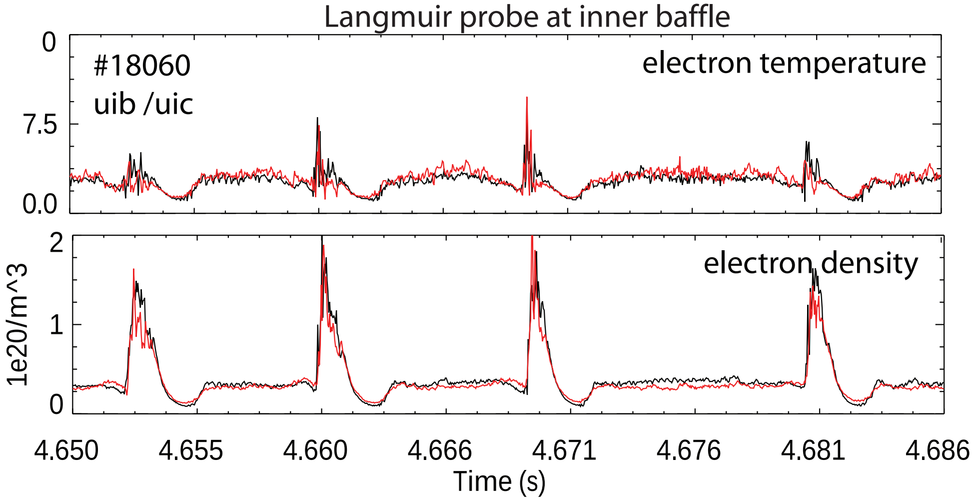
Real time observation

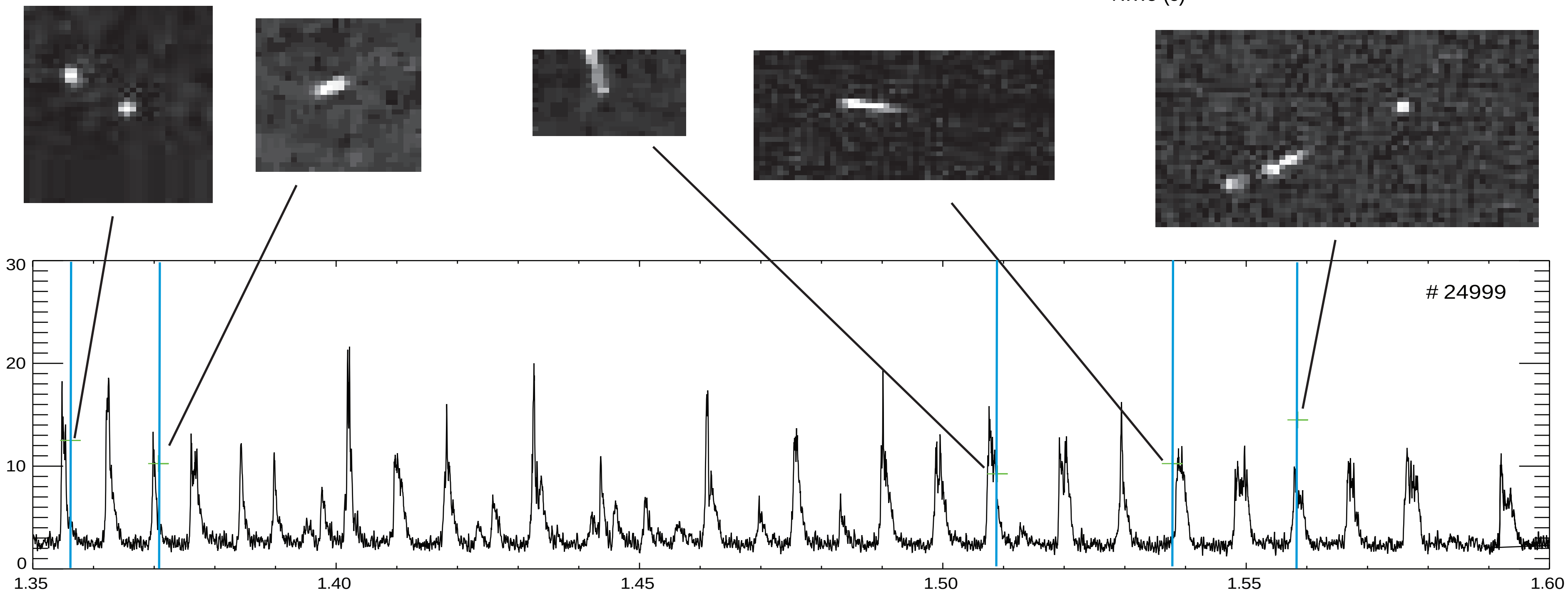
Arcs are correlated with ELM's

Example of 5 MW H-mode discharge
  11 events observed during discharge

average radiation on camera shows ELMs
events during onset of ELM

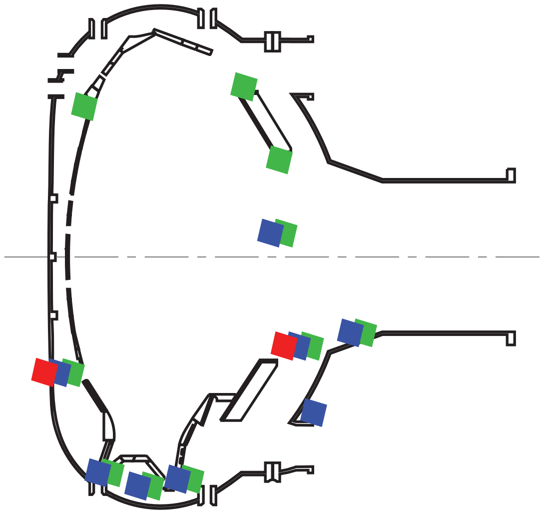
ELM at inner baffle: strong density rise
  can trigger arcing

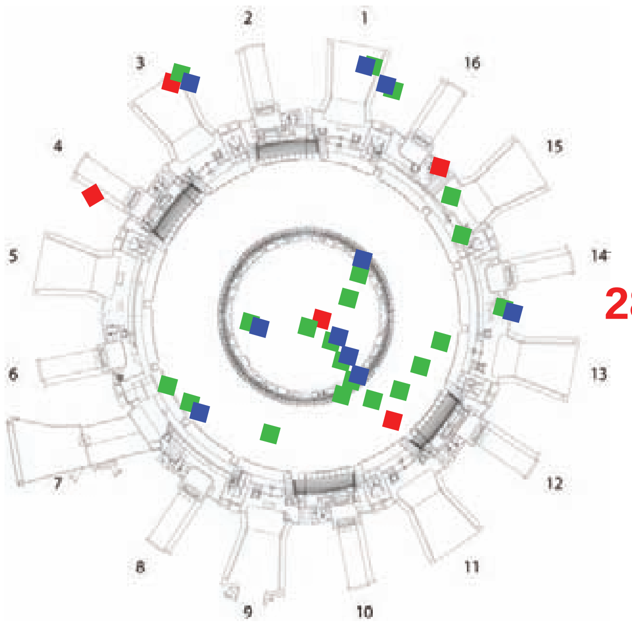




Dust: W Droplets

dust collection techniques





Filtered vacuum collection *(10 pcs.)*

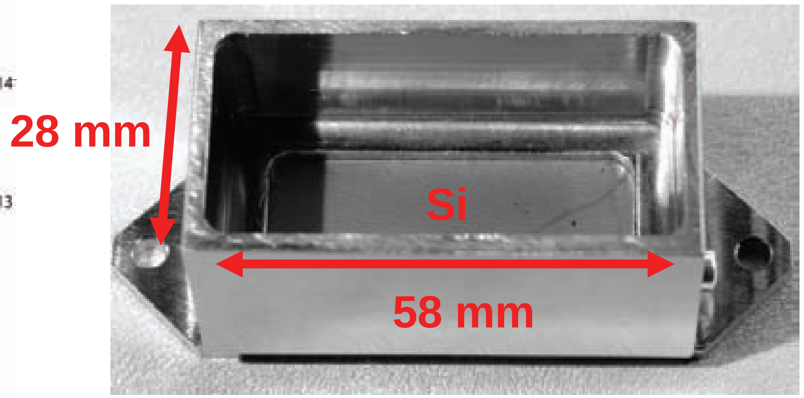
Adhesive carbon tabs *(41 pcs.)*

⇨ subsequent to filtered vacuum collection for dust collection ef
for dust collection ef ficiency assessment

Si wafer collectors *(5 pcs.)*

⇨ installed before campaign

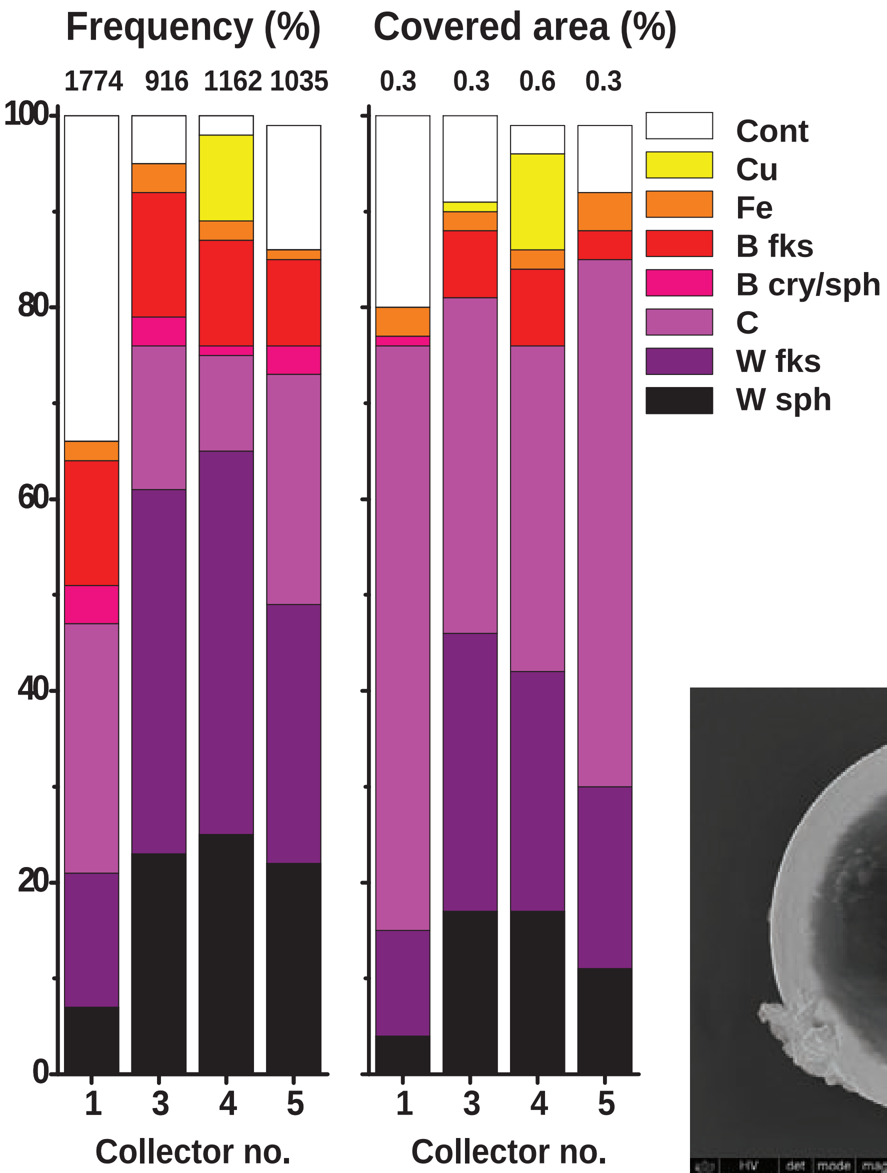
only results from Si wafers
simple technique, easy to evaluate



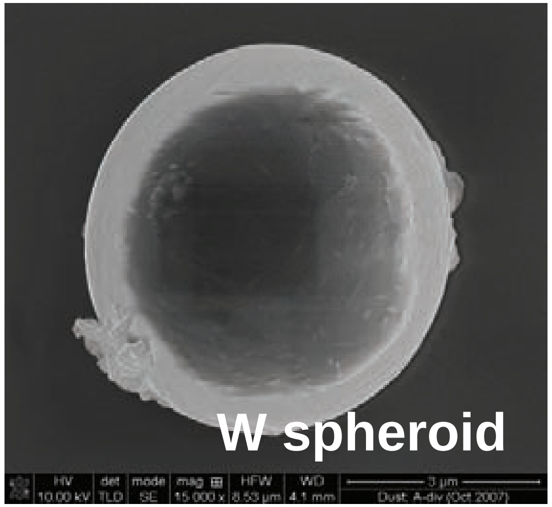
installed at
AUG and LHD
under installation at
DIII-D and JET

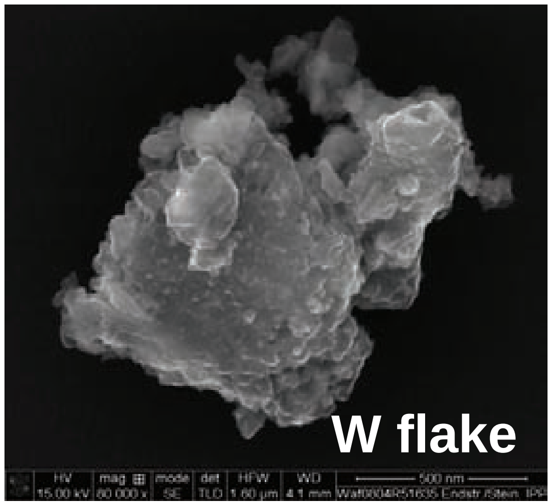
Dust: W Droplets

classification of dust



- automatical detection and evaluation of dust particles (~ 60 000 up to now)
- classification up dust species
  - PSI: 8 classes defined
  - IAEA CRP: definiton of classes will allow to compare dust from different devices
- many dust particle contain W
  - spheroids and flakes observed

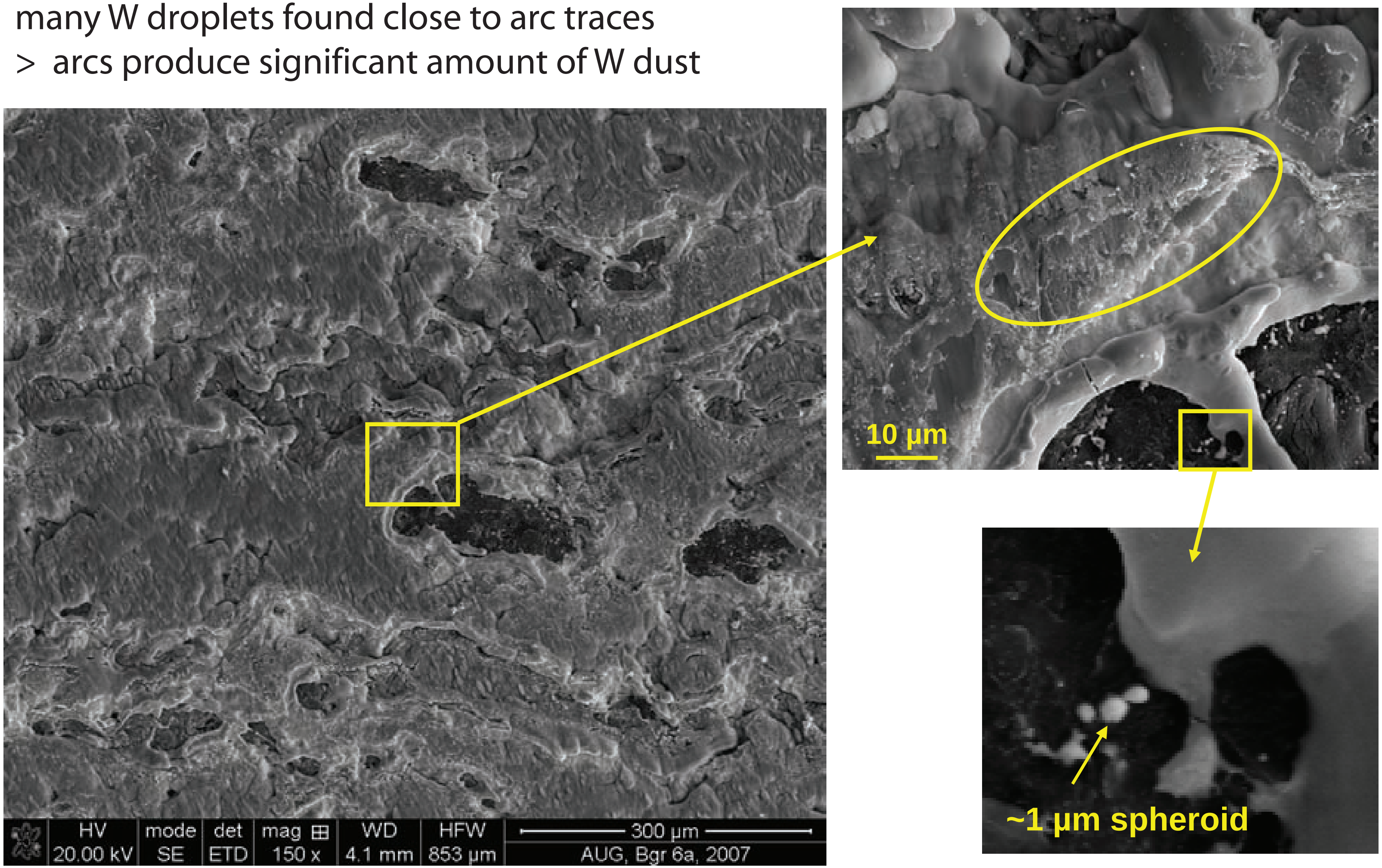




Dust: W Droplets

origin of W droplets

morphology of redeposited layers identical with W flakes
many W droplets found close to arc traces
> arcs produce significant amount of W dust



ASDEX Upgrade

Summary

IPP

Tile analysis

arc traces found at different locations
very inhomogenious
evaluation sheme developed
problem: classification of arcs

Real time observation

arcs observed
radiation by W droplets
or multiple arcs
triggered by ELMs

arcing dominates dominate erosion at inner baffle
weak erosion for pure tungsten (low surface resistivity)
deposited / isolation layer enhances erosion strongly
arcs at inner baffle produce 5-10 % of tungsten in AUG
arcs produce W droplets and flakes significant
fraction of dust observed

Future fusion reactors (ITER) will operate with
ELMs and metal PFCs
Role of arcs on PFC erosion and dust production
is not yet clear
intensified investigations needed