Broad-beam RBS/NRA results: overview of erosion/deposition patterns (MPG)

Martin Balden & Matej Mayer, IPP

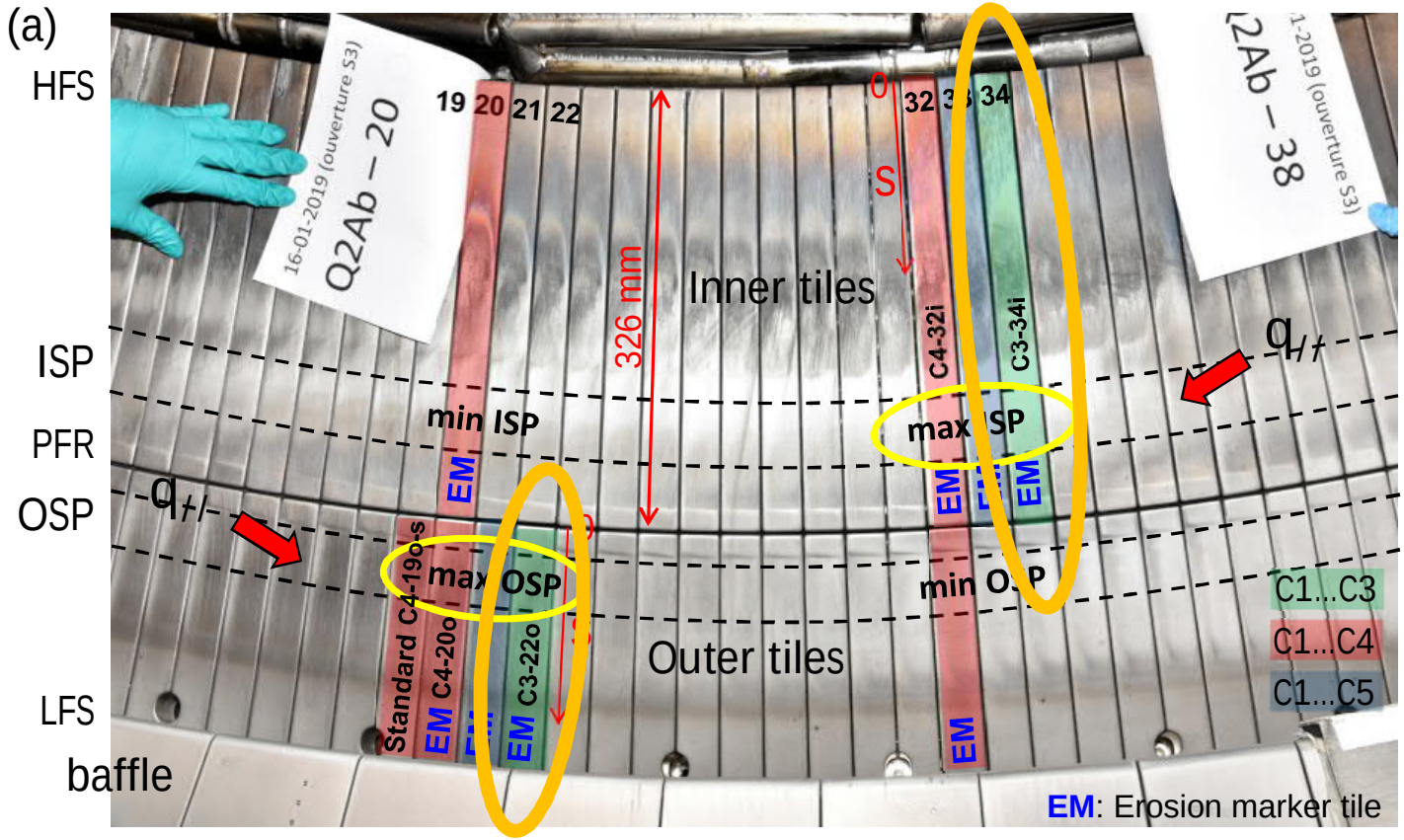
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

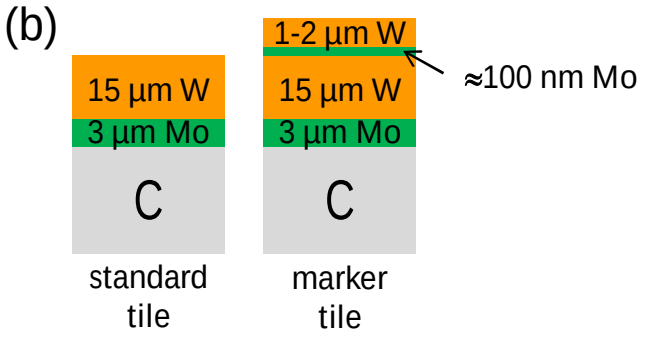
Content

- Tile geometry, nomenclature, measured positions
- IBA conditions and equipment on entry marker tiles
- Results on erosion/deposition pattern

Remark: Results already published;
Images partly taken from
[M. Balden et al., 2021, Phys. Sci. 96 124020]

Tiles – geometry and position in WEST





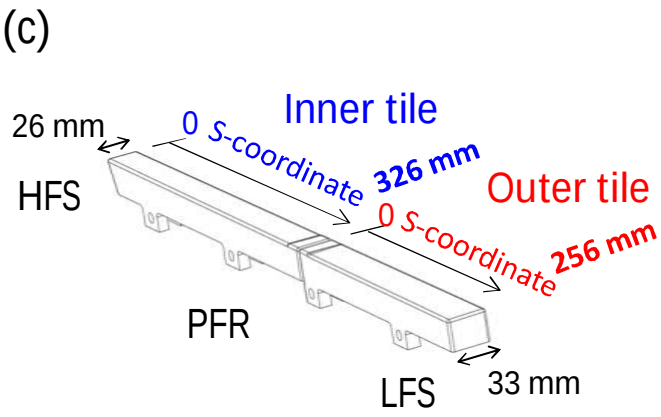
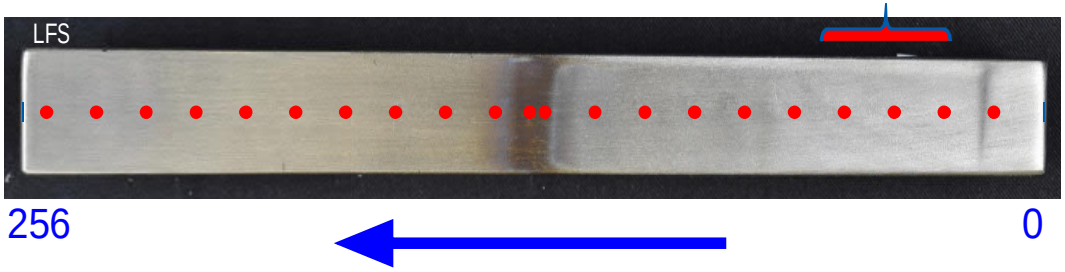


Fig. 1 of [M. Balden et al., 2021, Phys. Sci. 96 124020]

Tile geometry, nomenclature, measured positions

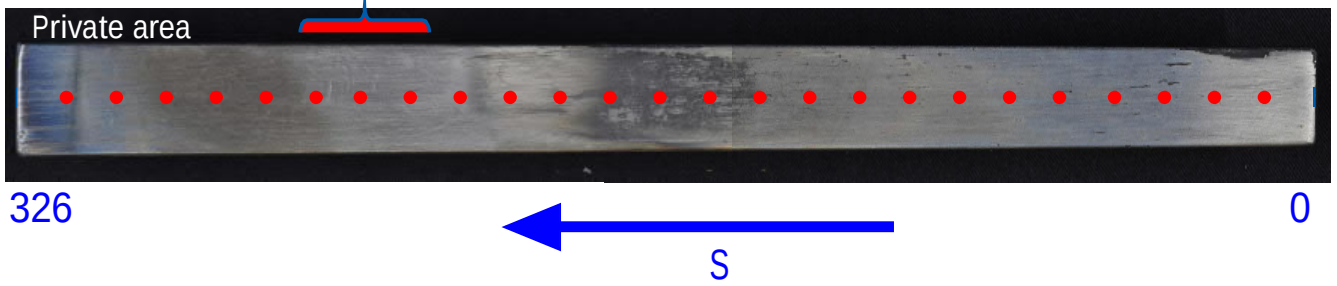
Erosion marker tiles exposed C1+C2+C3

C3-22o 941G142 (outer#22)



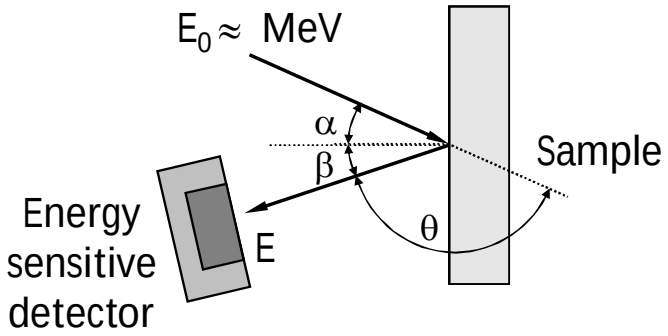
Positions of broad IBA

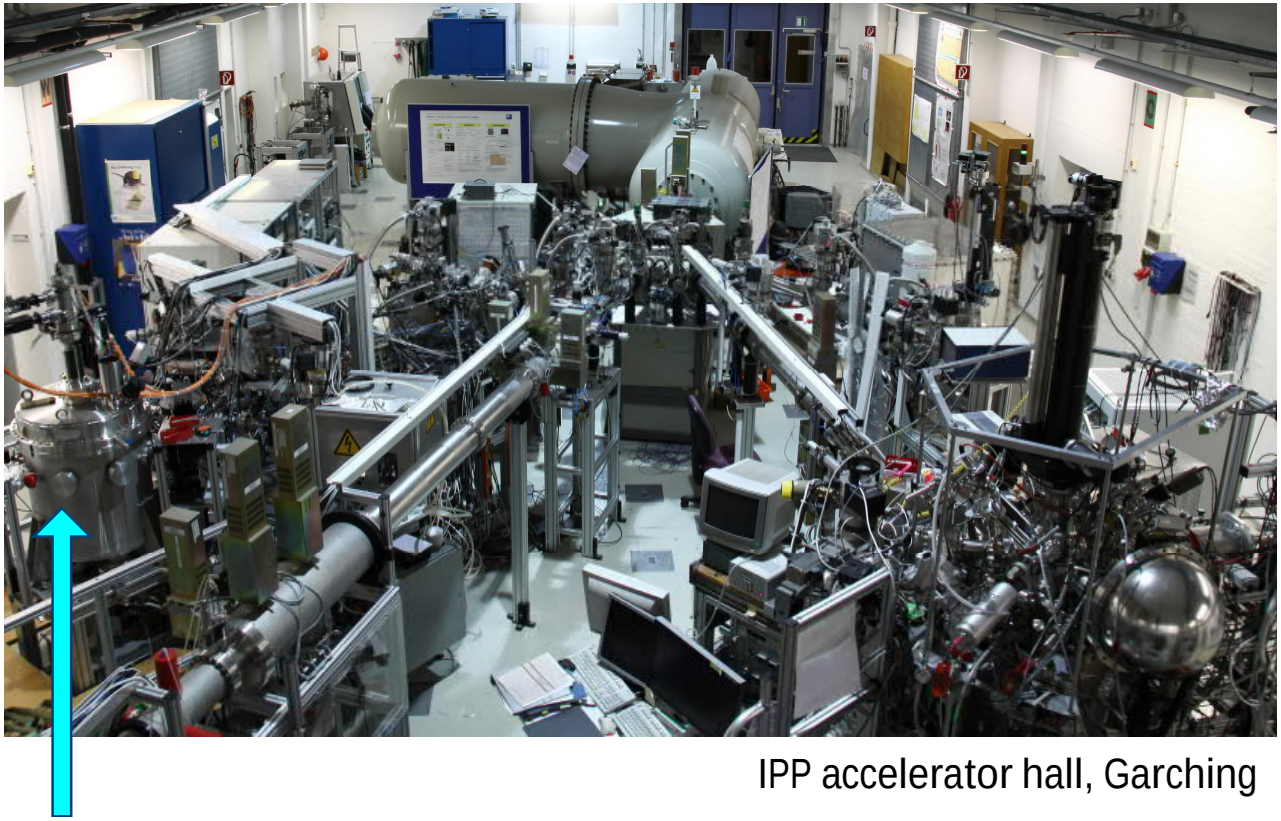
C3-34i 940G193 (inner#34)



IBA (ion beam analyses)

- Schematic of IBA



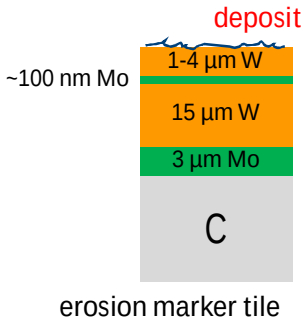


IPP accelerator hall, Garching

Ion beam analysis: RBS+NRA

- Measurement positions
  - On both tiles about every 12.5 mm (MB width) along central line
  - Spot size area ~2 mm^2
- IBA conditions
  - RBS: 3.0 MeV protons at 165° (1.5 MeV protons at 165°; 2.5 MeV ^{3}He at 165°)
  - NRA: 2.5 MeV ^{3}He at 150°
- Obtained information
  - Amount of W above thin Mo interlayer
  - Amount of D, B, C (partially with depth information; D < 3 µm in W; B, C <1.5 µm in light matrix)
  - Presence of O
- Remarks
  - Roughness smears out the “signal” of thin Mo interlayer
  - W and Mo thickness on Si witness sample → not much in common with layer thickness on WEST tiles → pre-characterisation of tiles for proper erosion measurements
  - Oxygen amount derived only indirectly from shape of 3.0 MeV RBS unexplainable by B and C alone

IBA performed and evaluated by Matej Mayer

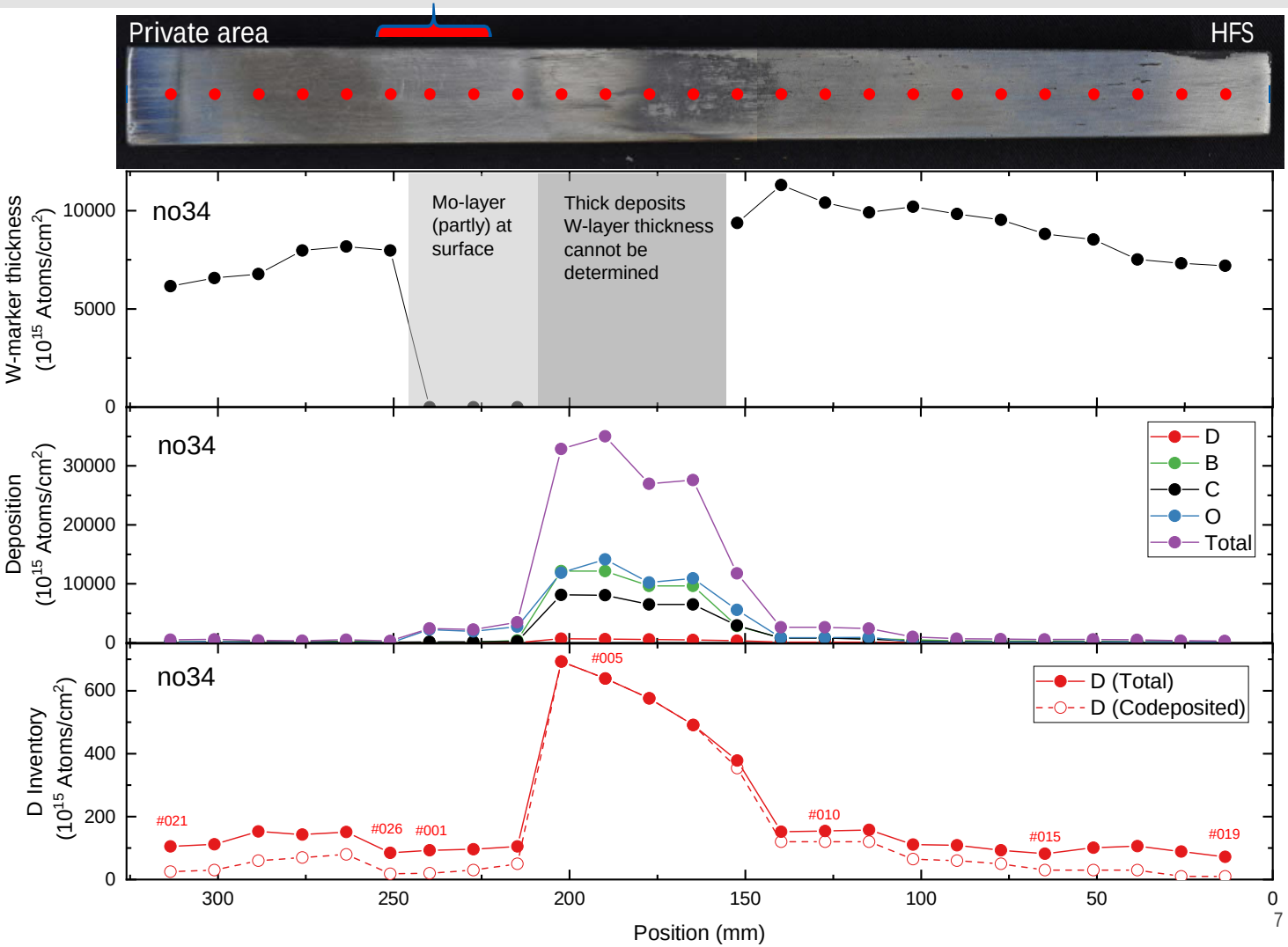


erosion marker tile

RBS = Rutherford backscattering spectroscopy NRA = Nuclear Reaction Analyses

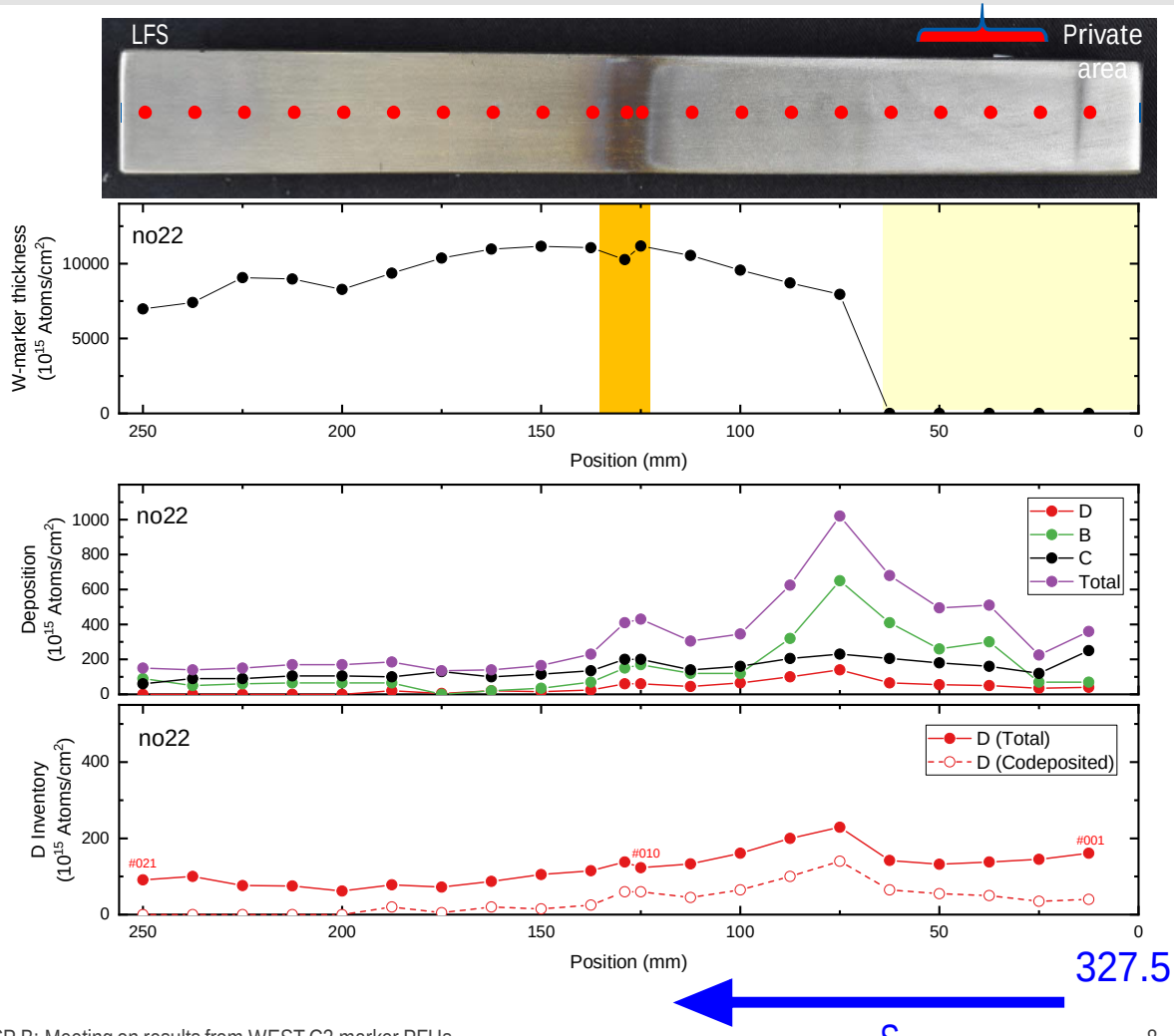
Results: Erosion/deposition pattern inner tile – C1+C2+C3

- Main statements: C3-34i
  - Initial W layer thickness varies across tile (?)
  - D depth profile: surface peak (in deposit) and tail (in W: 0.2-0.5%)
  - D also beyond ~3 µm
  - Mo interlayer partly at surface (grey area, #001-003)
  - Too rough and too thick deposit (dark grey area, #004-009)
  - Total thickness of deposit quite robust (dark grey area, #005-009)



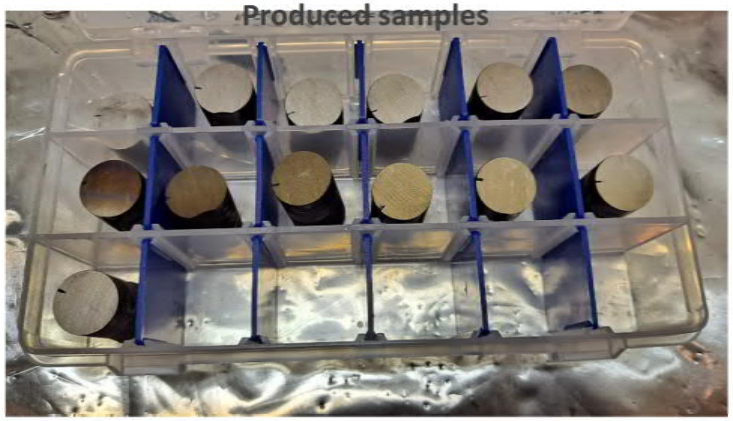
Results: Erosion/deposition pattern outer tile – C1+C2+C3

- Main statements: C3-22o
  - Initial W layer thickness varies across tile (?)
  - D depth profile: surface peak (in deposit) and tail (in W: 0.2-0.5%)
  - D also beyond about 3 µm
  - Mo interlayer seem to be (more or less) completely eroded around outer strike line (yellow area, #001-005)
  - Brown area (#010-011): effect on RBS spectra, but element not identifiable (→ no clarification by EDX)



Cutting of the “C3 marker tiles”

- **C3 marker tile cut into smaller pieces for further analyses**



Erosion/depostion pattern overview: Published

Fig. 2

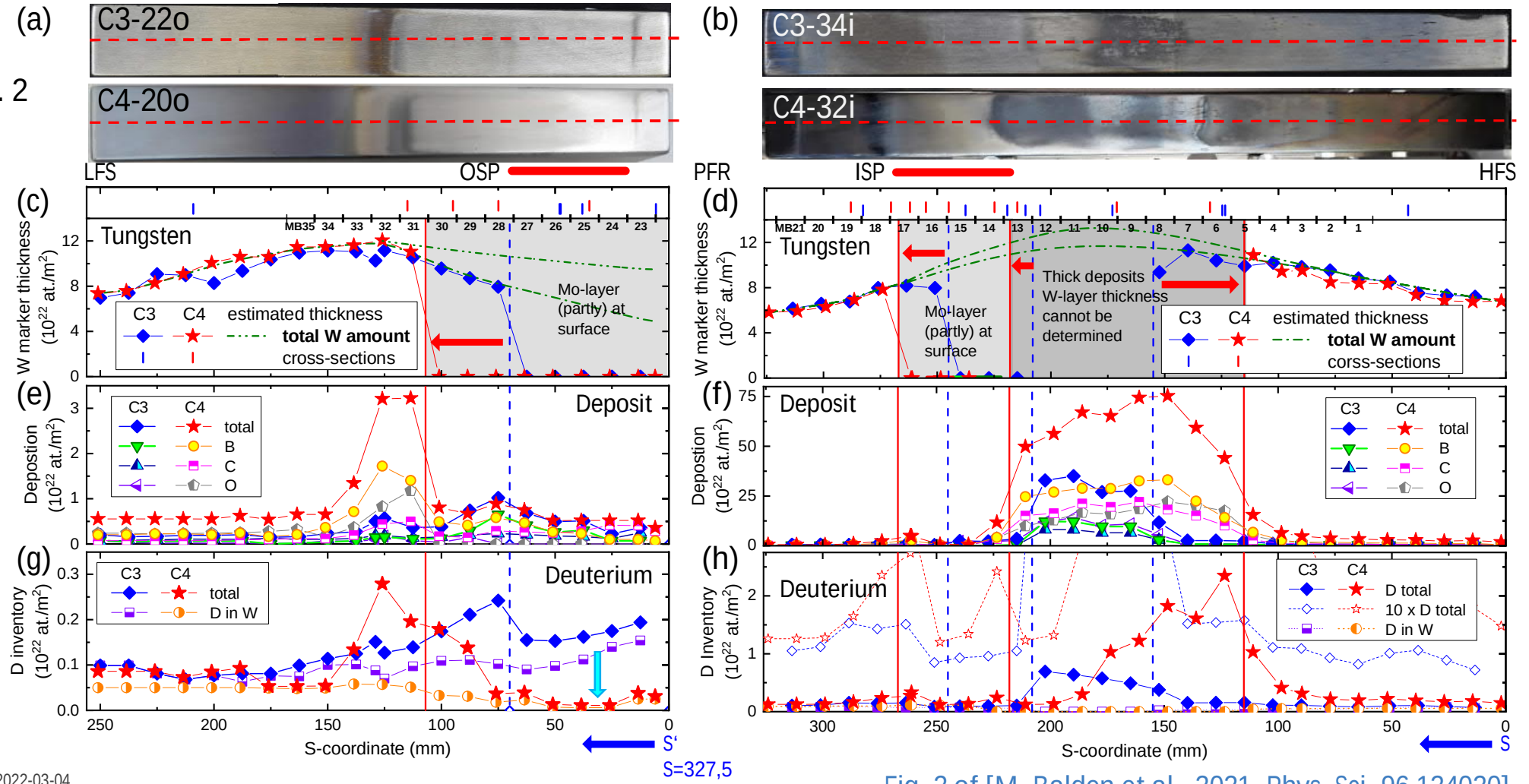


Fig. 2 of [M. Balden et al., 2021, Phys. Sci. 96 124020]

SEM/EDX results for overview of surface modifications (MPG)

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Content

- Aim of microscopic analyses on entire marker tiles (SEM assisted by FIB and EDX + CLSM)
  - Analyses position and equipment
- Prelude: “initial” marker layer
- Results on erosion/deposition pattern
  - Thick deposition
  - Erosion
  - Arcing

Remark: Results already published
[M. Balden et al., 2021, Phys. Sci. 96 124020]

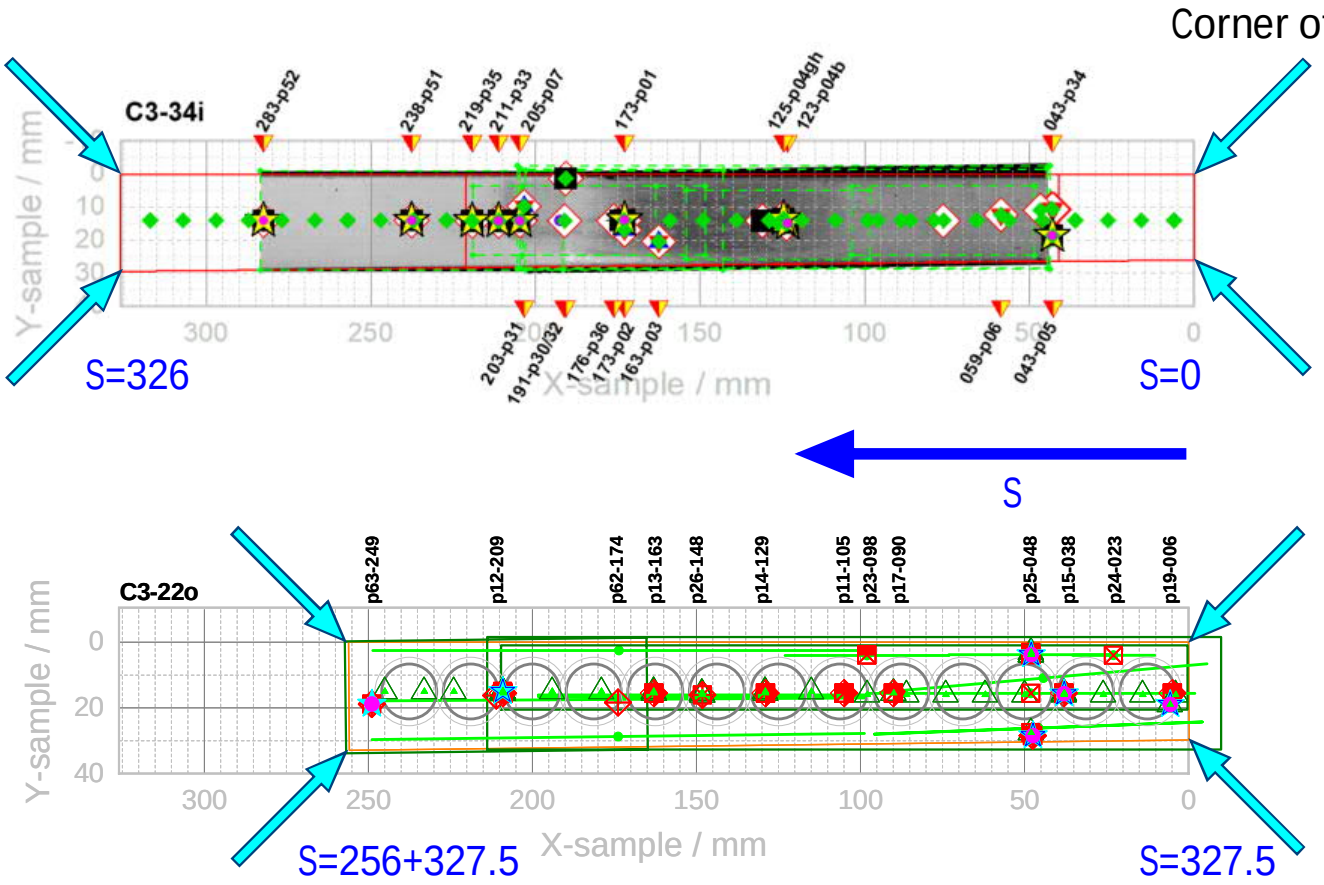
Aim of microscopic analyses on entire marker tiles

- SEM + EDX + FIB-cross-sectioning + CLSM
  - Many positions on each tile analyzed by SEM magnification series and EDX-mapping
  - Most of those positons also analyzed by CLSM to obtain 3D profile data
  - Cross-sectioning performed with FIB for selection of positions ⇨ analyzed with SEM/EDX
  - Many images for documentation by "ATLAS" as line and areal scans

- Aim of microscopic analyses
  - Assist, confirm and complement ion beam analyses
  - Provide images for post-processing to support following analyses after cutting the tile into smaller samples

SEM = Scanning Electron Microscopy EDX = Energy Dispersive X-ray spectroscopy FIB = Focused Ion Beam CSLM = Confocal Laser Scanning Microscopy

Overview of all position of microscopic analyses before cutting



- sample edges
- Atlas/line analysis area
- images magn series
- EDX-5kV
- EDX-20kV
- 20kV-magn series
- Atlas/mid
- tilted magn series
- cross-section
- CLSM
- cross-section-EDX
- x-pos

1) sample analysis area
- edges

2) Atlas
- Atlas-mid
- Atals-area
- Atlas-line

3) cut+more
- cut-y-i
- cut-y-o

4) CLSM/IBA
- CLSM
- % (2)

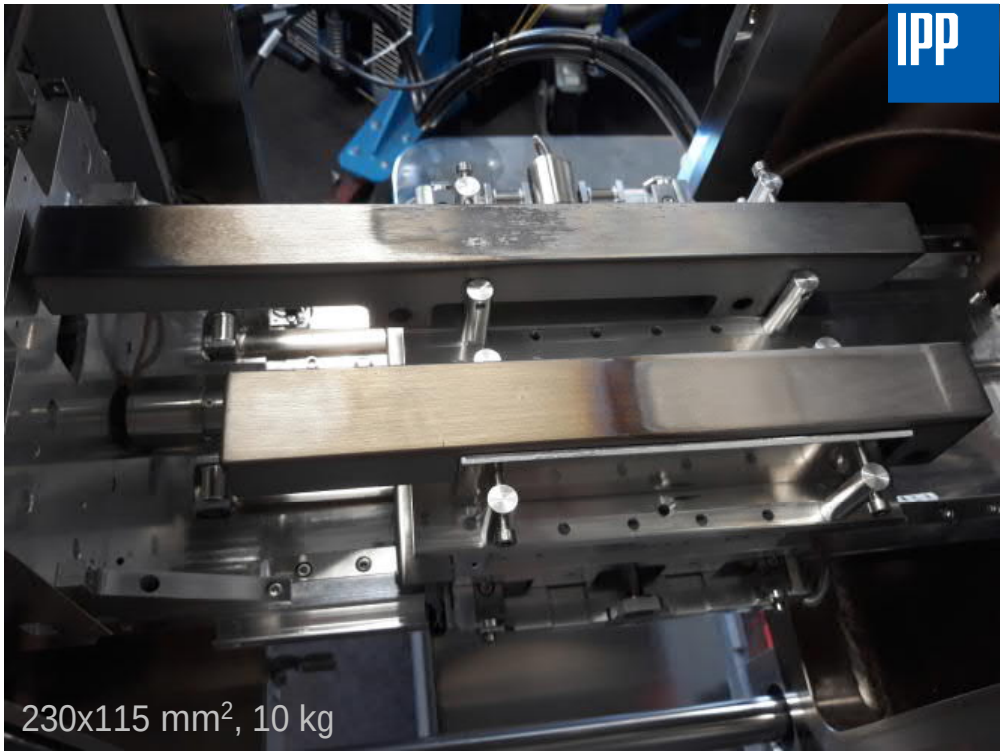
5) SEM-EDX
- SEM-5kV-magn-series
- EDX-5kV
- SEM-20kV-magn-series
- EDX-20kV

6) CS
- SEM-tilt magn series
- FIB cross-section
- EDX-CS
- CLSM

SEM/FIB with EDX

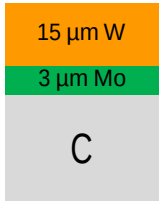
- AURIGA lab

WEST marker tiles mounted on AURIGA heavy-load stage



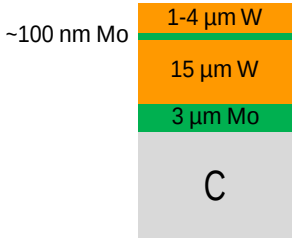
Prelude: Morphology of „initial“ marker layer

- Surface topography of maker coating vs. standard coating
  - Standard: Edgy surface (crystallites)

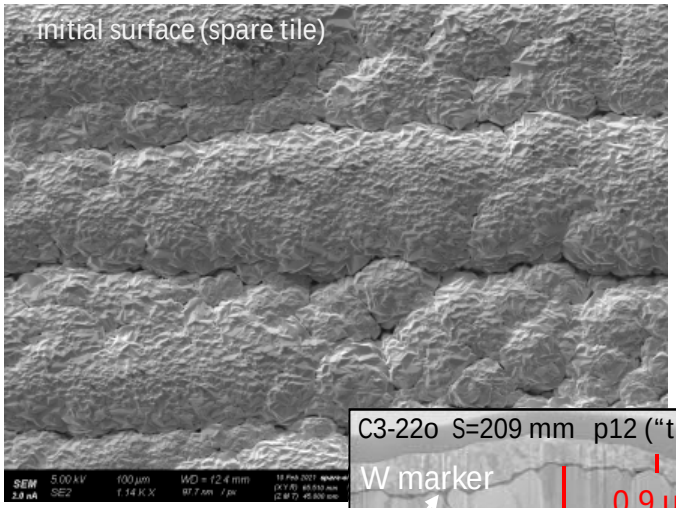


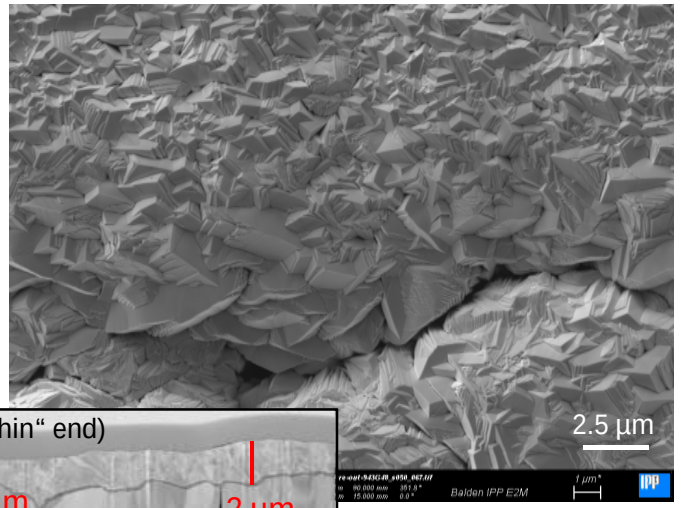
standard tile

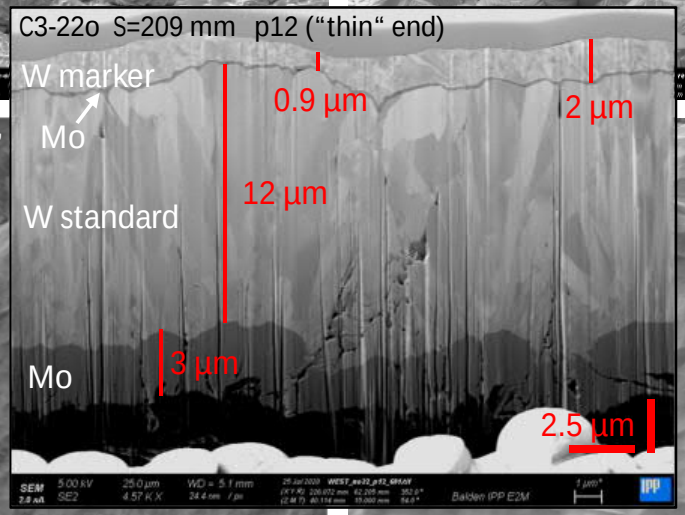
  - Marker: Valley structure (smoother)

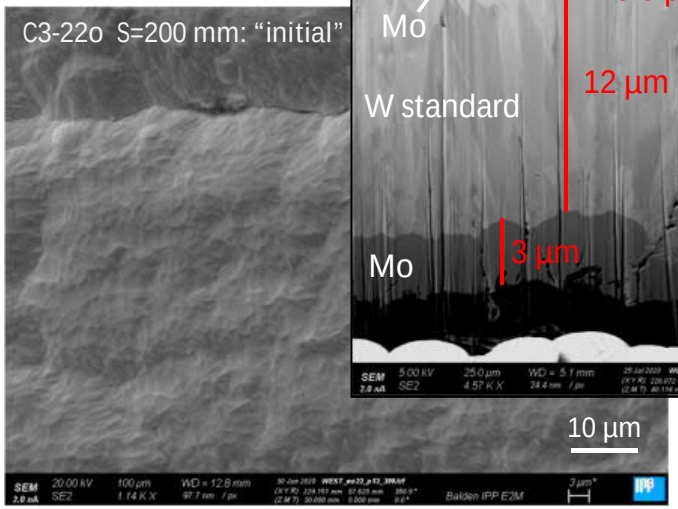


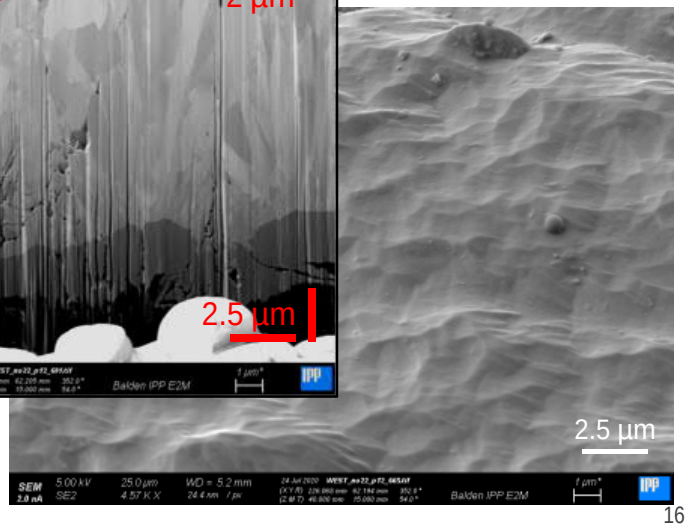
erosion marker tile





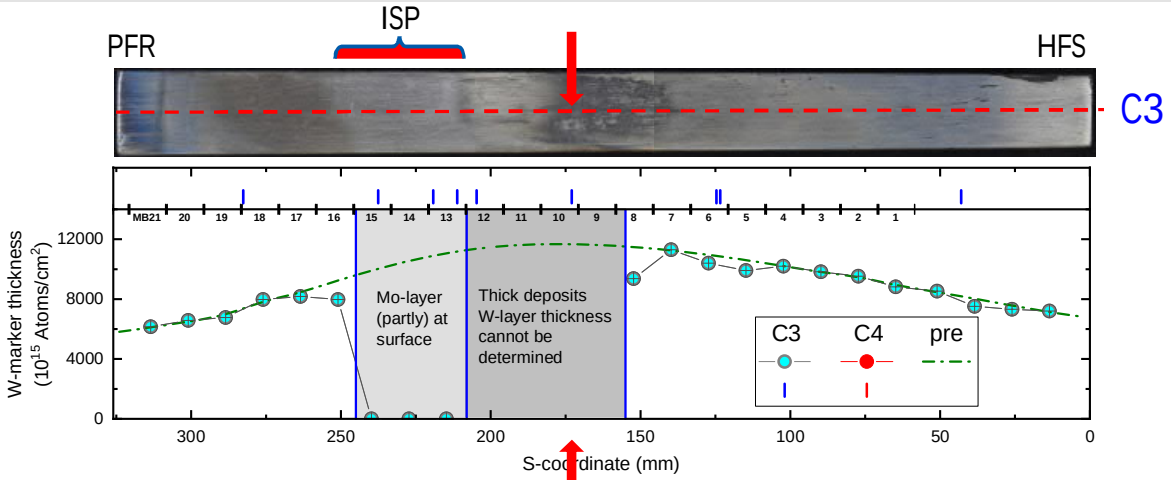


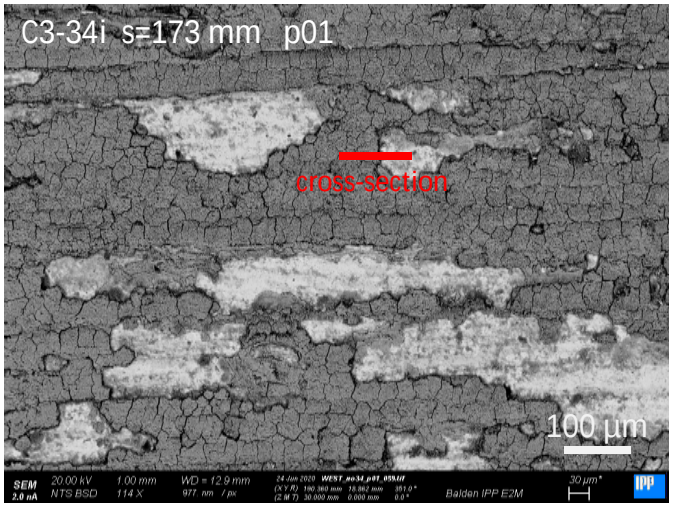




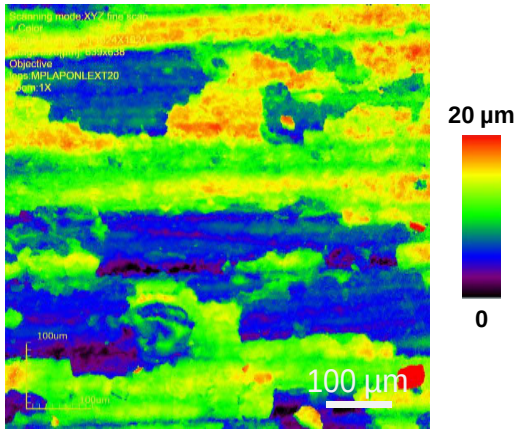
C3-34i: SEM results of inner divertor marker tile after C3 campaign

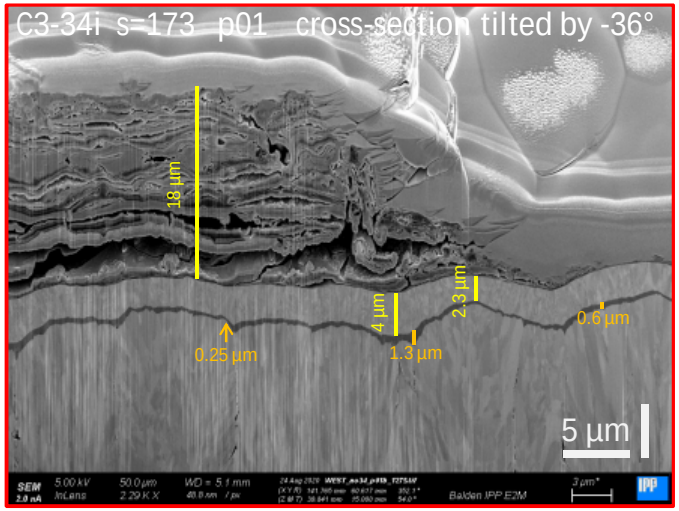
- Thick deposit
  - Thickness: >10 µm
  - Partly delaminated
    → peeled-off area is enhanced in B
    (multilayer structure; history)
  - Crack network (only through deposit layer):
    no effect on W/Mo-layers underneath





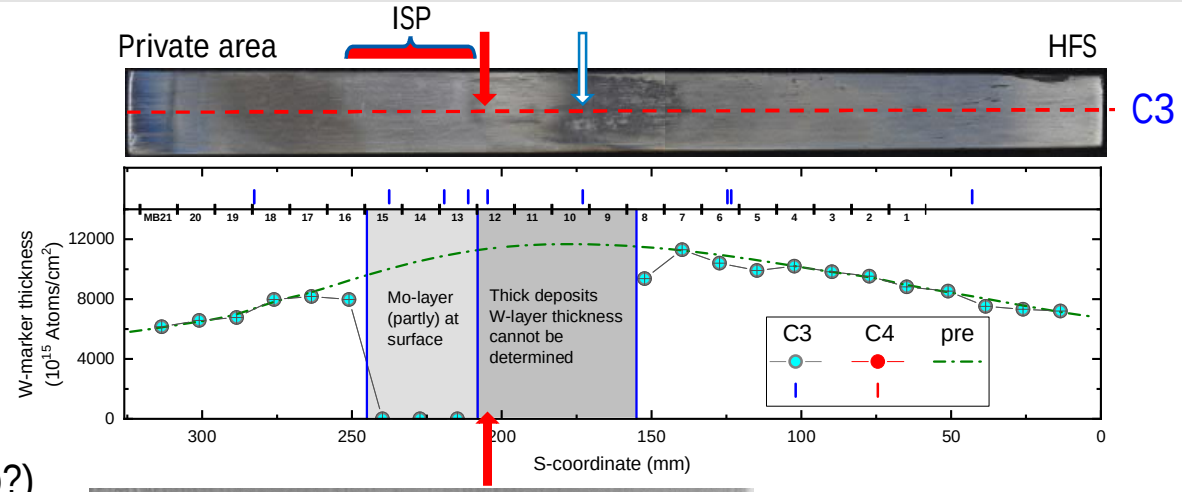
CLSM 3D-data

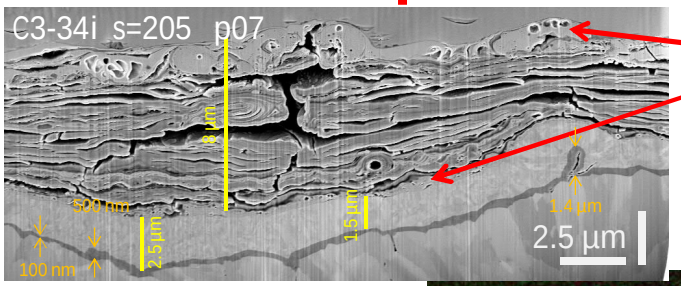




C3-34i: SEM results of inner divertor marker tile after C3 campaign

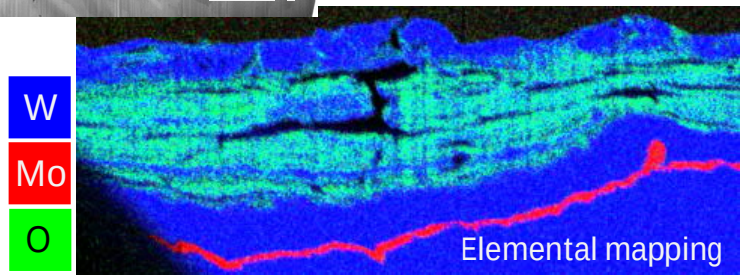
- Thick deposit
  - Thickness: >10 µm
  - Partly delaminated
    → peeled-off area is enhanced in B
    (multilayer structure; history)
  - Crack network (only through deposit layer):
    no effect on W/Mo-layers underneath
  - Elements in the deposits are
    mainly B, C, W and O; additional some Cu (Mo?)
  - Top layer on deposit with high W concentration
    contain sometimes many pores
    (danger of confusion with feature due He);
    also pores in first deposition layer on W-cover
    marker layer





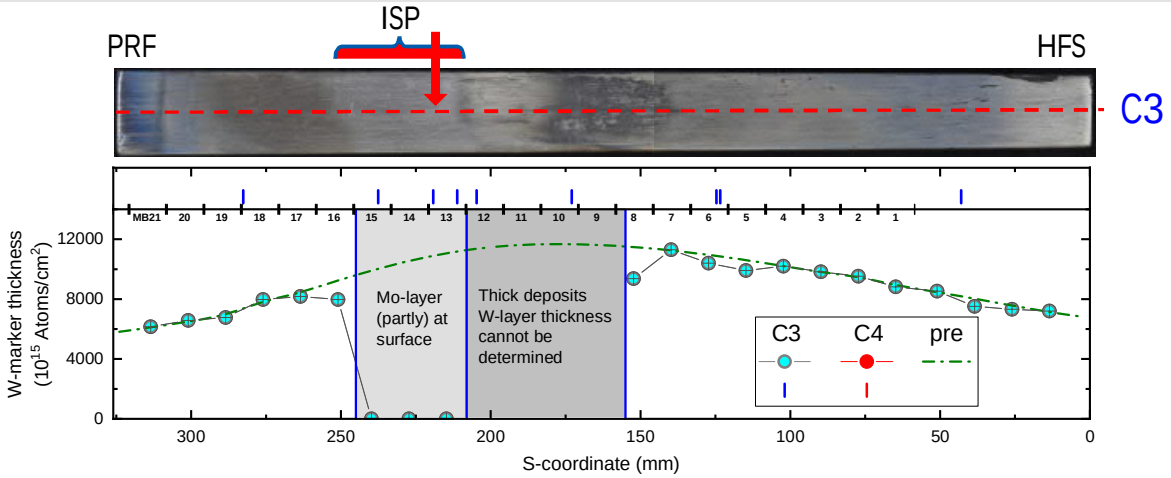
Pores

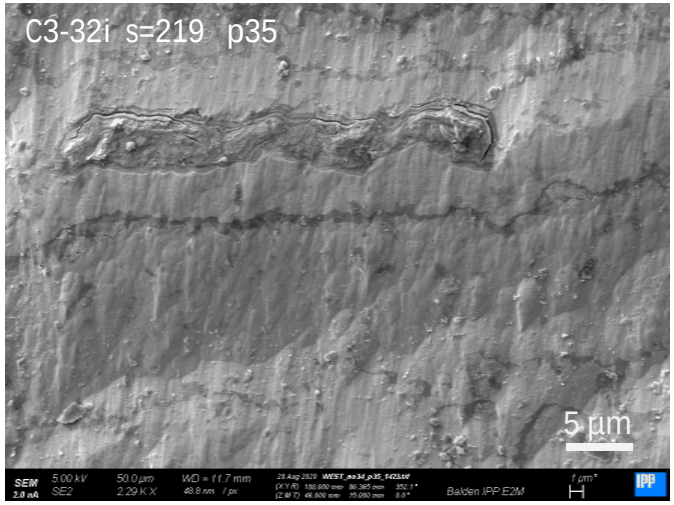
- Coating thickness
  - W-cover marker layer luckily thicker than designed
    (1-4 µm instead of 0.9 µm)

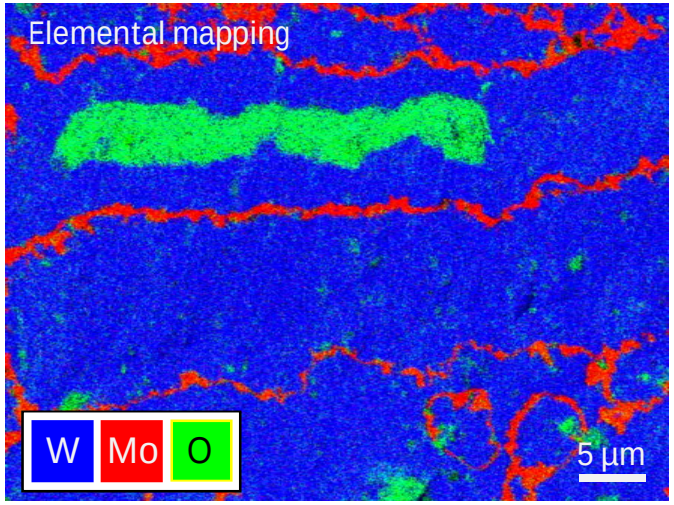


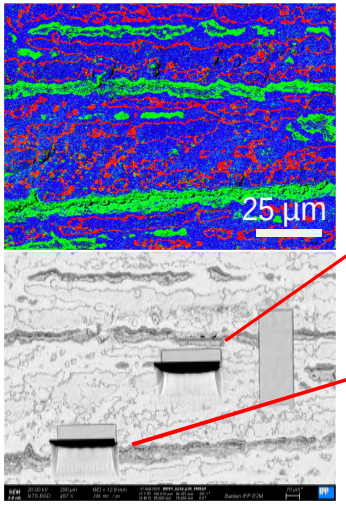
C3-34i: SEM results of inner divertor marker tile after C3 campaign

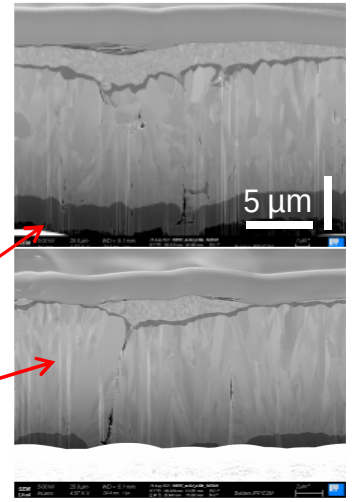
- Strong erosions
  - Strong erosion easy to detect: > 1 µm
    (Mo-lines good visible in 20 kV-BSE images)
  - Deposition beside the erosion
    (due to roughness)





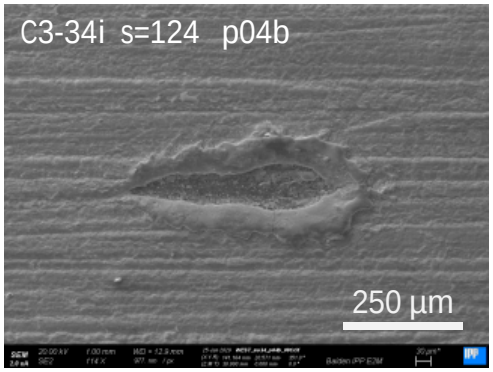


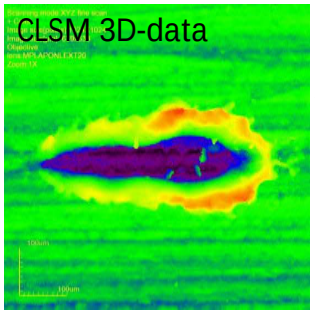




Further observations: Arcing

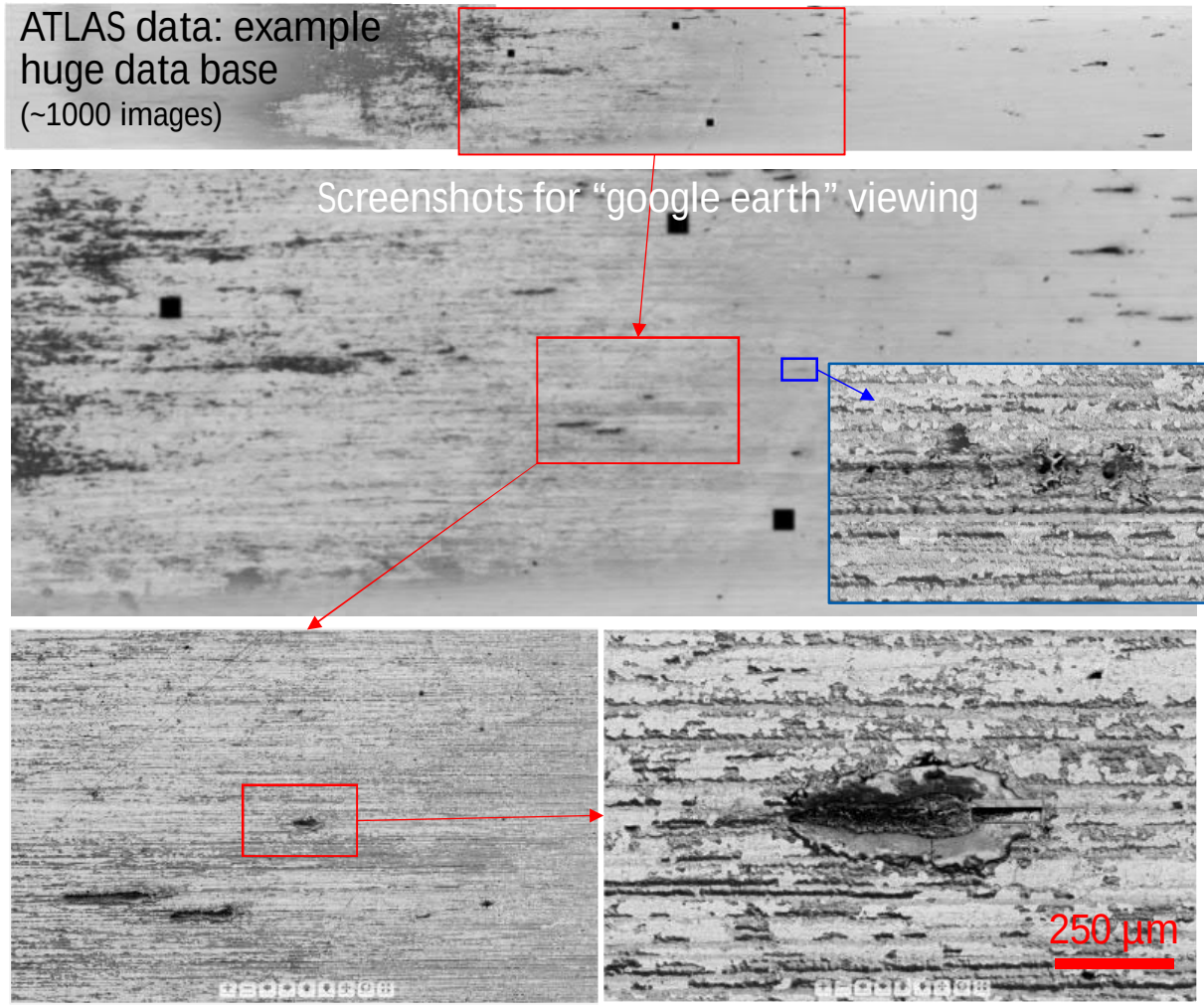
- Strong arcing on inner tiles
  - Arcs burning through stack of coating (>20 µm deep)
  - After C3: Many (>100) such traces (area ~1%)





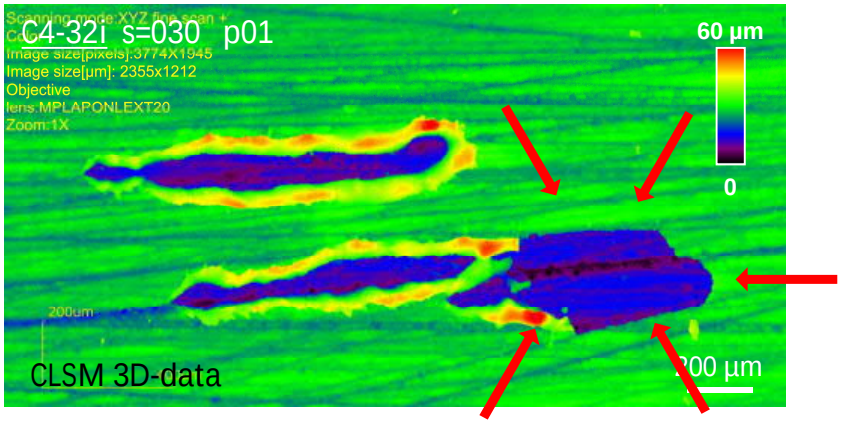
Height data obtained before cross-sectioning

- Example of “ATLAS” large area scans
  - Potential of evaluation later on and post-processing for supporting following analyses e.g. density of strong arcing

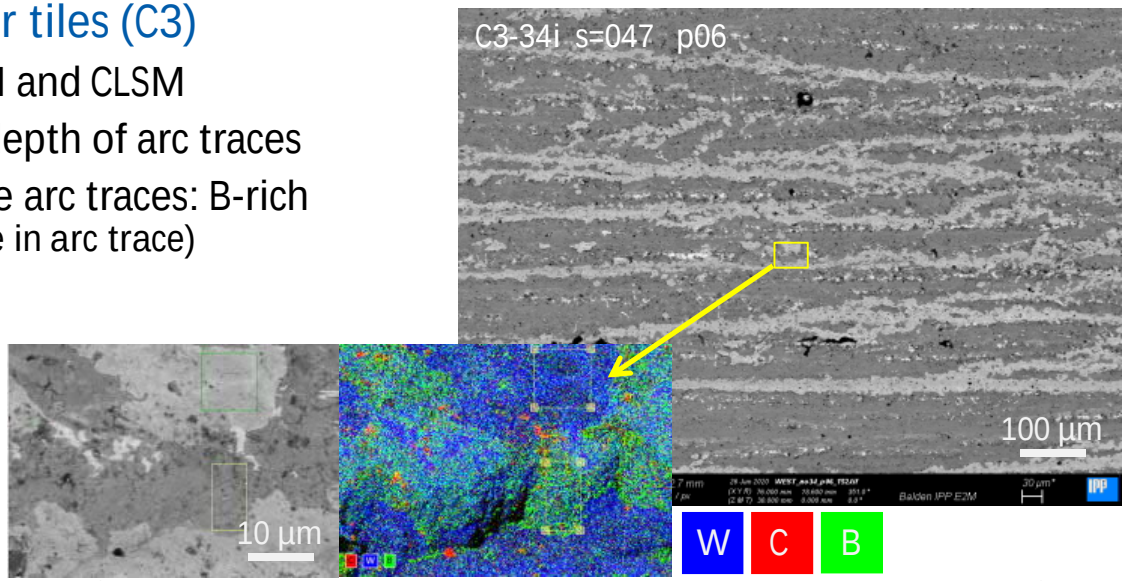


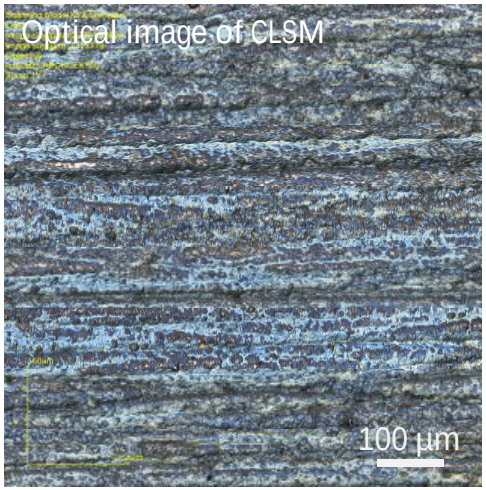
Further observations: Arcing

- Strong arcing on inner tiles
  - Arcs burning through stack of coating (>20 µm deep)
  - After C3: Many (>100) such traces (area ~1%)
  - Arcing could lead to delamination (occasional observed)



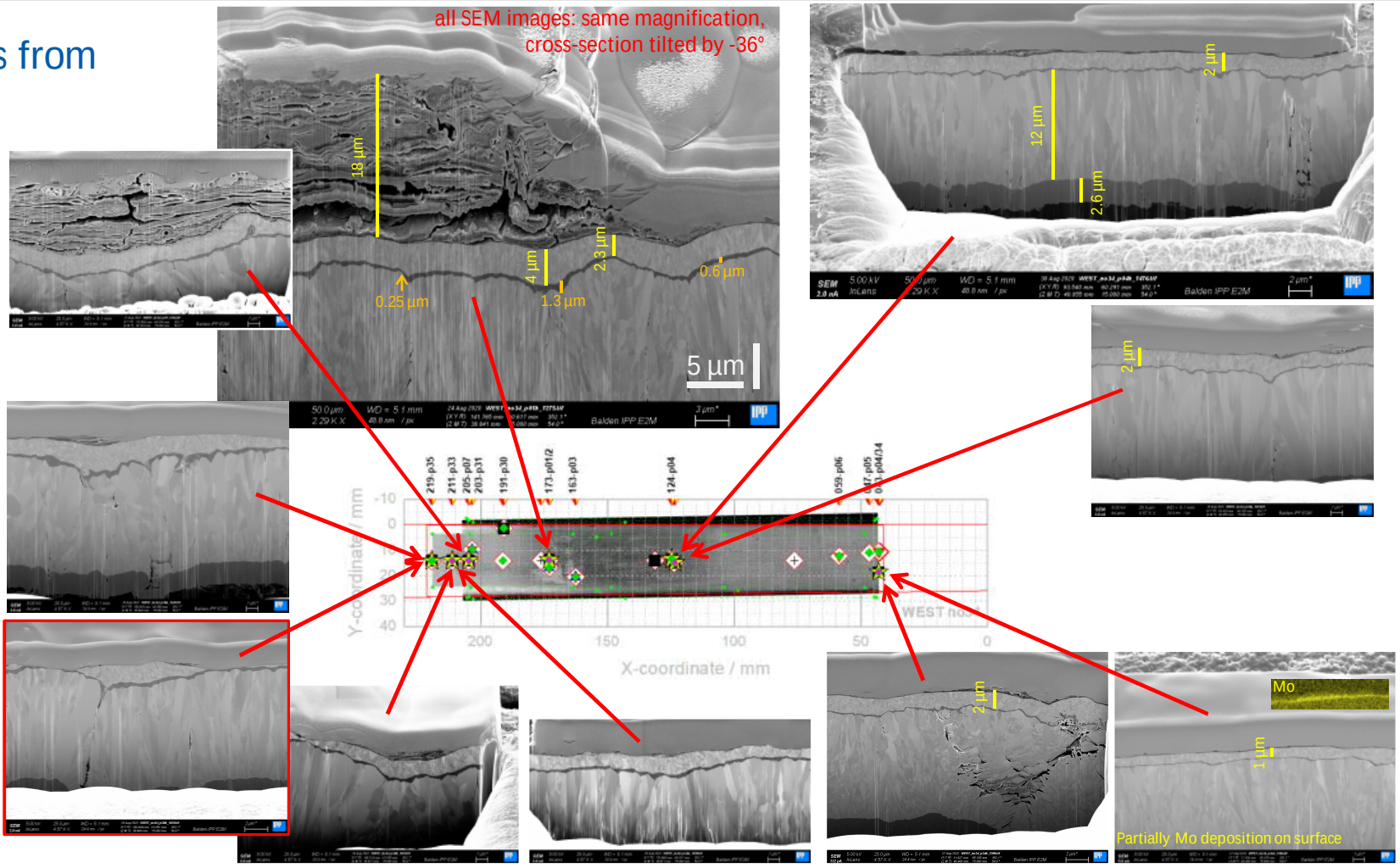
- Weak arcing on inner tiles (C3)
  - Arcs visible in SEM and CLSM
  - No measureable depth of arc traces
  - Deposition outside arc traces: B-rich (composition change in arc trace)



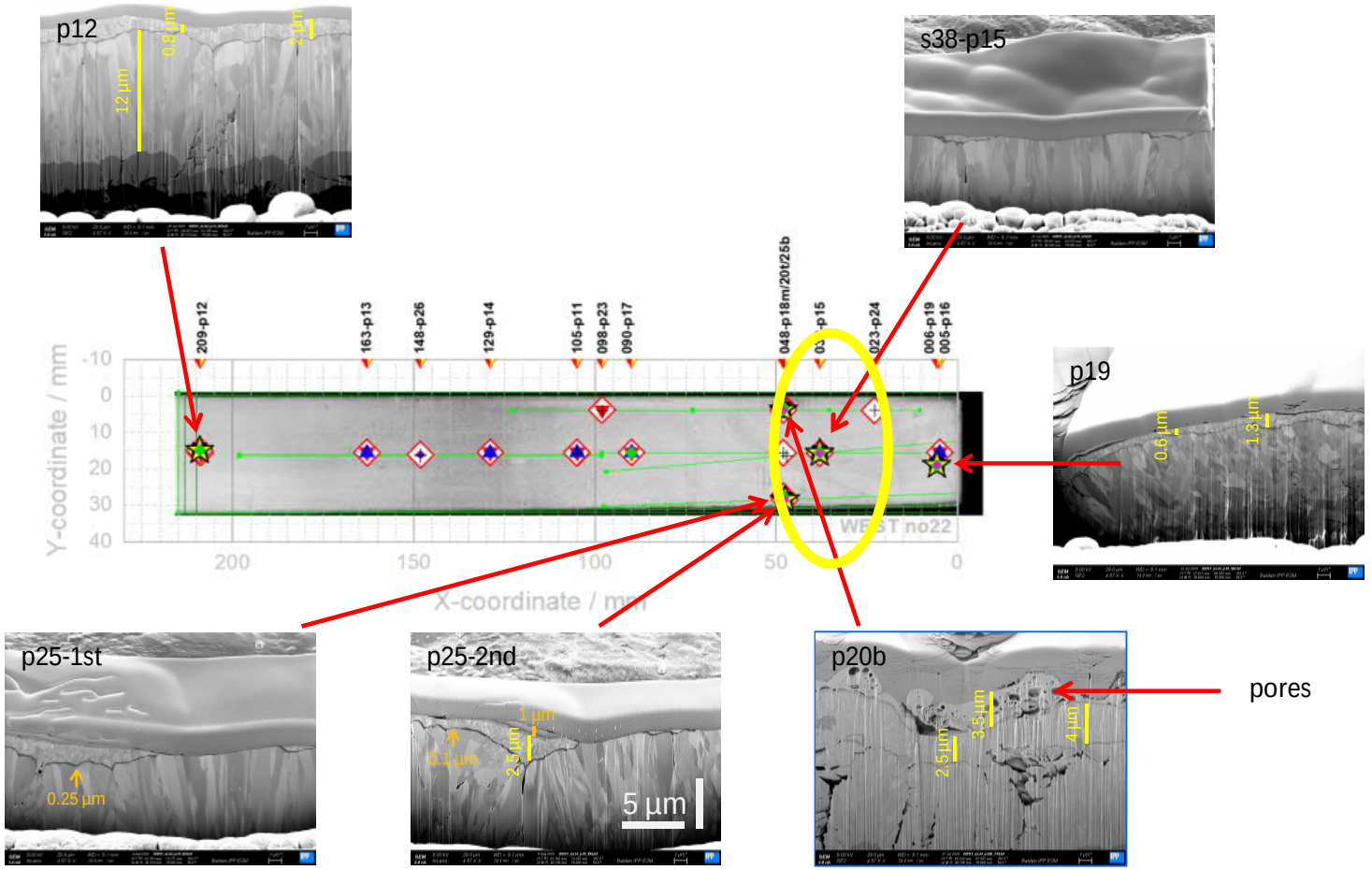


C3-34i: Inner erosion marker tile after C3: Cross-sections

- Remarkable features from cross-sections
  - Smoothing of top W layer by erosion
  - Marker layer partially removed
  - Thick fragile deposition layers
  - Despite strong erosion (> 2 µm), deposition layers



C3-22o: Outer erosion marker after C1+C2+C3: Cross-sections



Erosion/depostion pattern overview: Published

Fig. 2

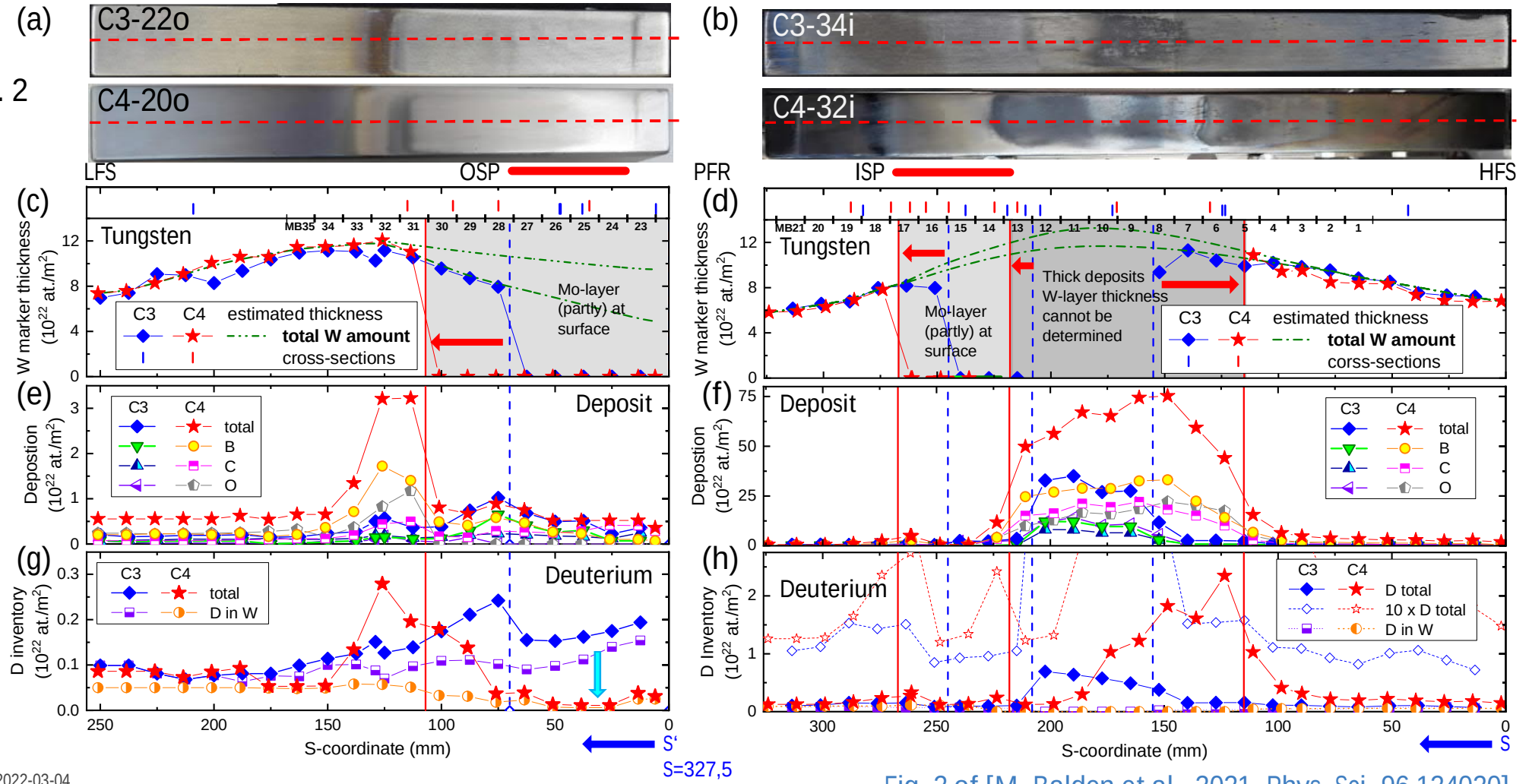
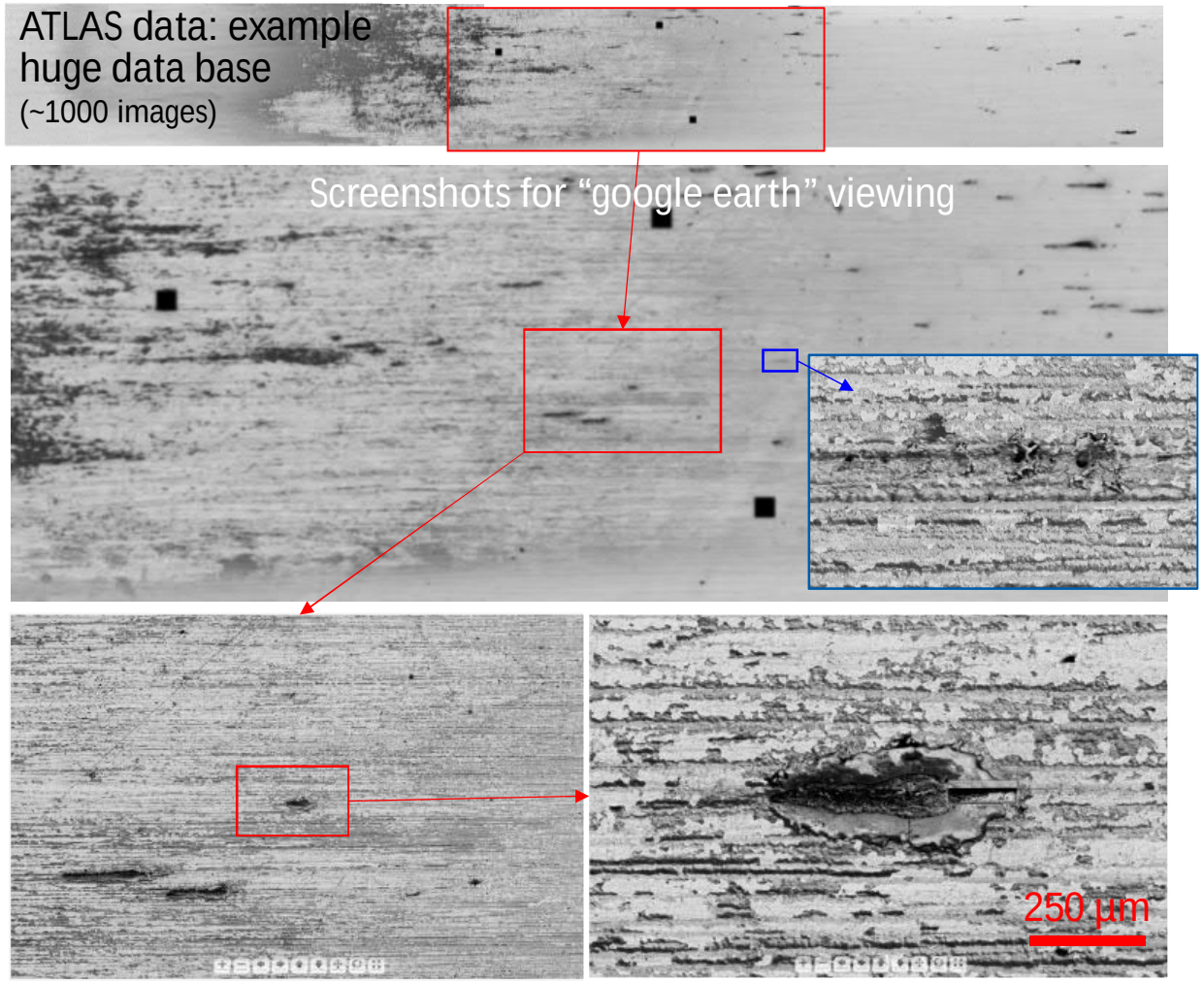


Fig. 2 of [M. Balden et al., 2021, Phys. Sci. 96 124020]

Reminder ATLAS data



Outlook

- SEM analyses on the side (poloidal gaps) of the tile after core drilling
  - Imaging and EDX data acquired, but not finally evaluated
  - Probably broad beam IBA will be done, too