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# W dust studies at IPP:
# On collected AUG dust and produced by arcing

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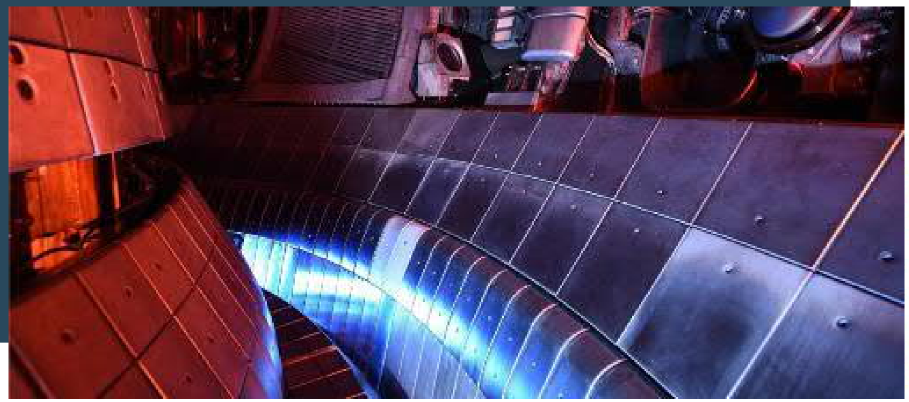

EUROfusion

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# Motivation

## Dust: Safety & operational issue

- **Knowledge of amount, composition, microstructure & … of dust particles needed**
- **Production processes to be elucidated** *(peeling-off of deposits, arcing, melting, cracking …)* **and changes during transport in device** *(change in microstructure, composition, surface area, …)*

→ **Prediction for future devices**

→ **Risk assessment**

## Here focus on two topics

- **Collected dust from AUG**
- **Studies of arcing on W in AUG and lab**

# Preliminary notes to "dust"

- **How to define "dust"?**
- **What has to be counted as "dust"?**
  - *only mobile / loose particles vs. deposits*
  - *particles from working in device* "**debris**"
    *vs. due to plasma operation* "**dust**"
- **Which production processes are possible / relevant** *(flaking deposits, arcing, melting, agglomeration in plasma, …)***?**
- **How to separate particles from different processes?**
- **What are the "right" properties,**
  *(e.g. mass, number, surface area, T retention, …)*
  **describing dust for which assessed risk?**
  **…**

- **Carbon time**
  → ***large amounts; flaking off of deposits***
- **W surface (AUG)**
  → ***strong reduction of dust amount***
  → ***deposits, droplets (arcing, melting)***
- **WEST: thick deposits**
  → ***with C, O, B, W, … but also nearly pure W***
  → ***operational issue!***
- **Dust collection: *vacuum cleaning* *sticky tapes, collector plates***

→ **Biased by their collection efficiency!**

→ **Microscopy on individual particles for statistically relevant number of particles**

# Collected dust from AUG

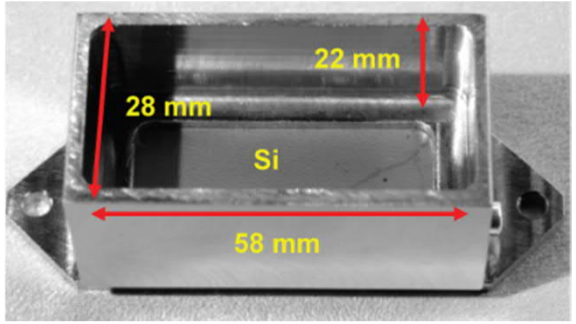
# Strategy of dust collection at AUG with W wall & analyses

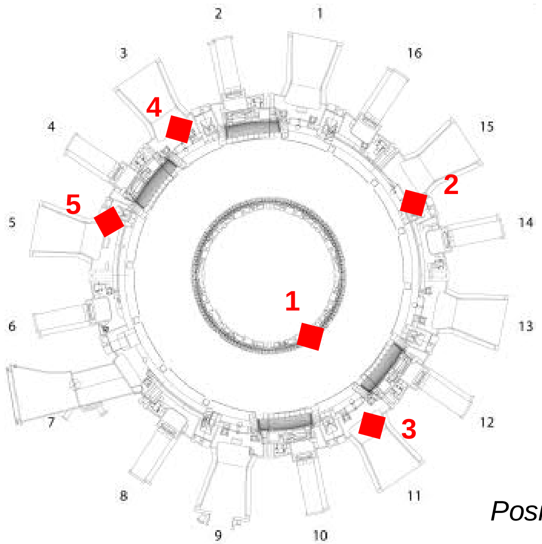
- **Collector boxes with Si plates**
  *installed at various positions around the torus (campaign-integrated)*
- **The more collectors the better the predictions (How representative?)**

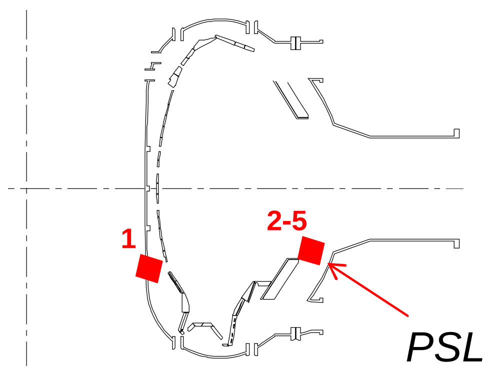
- **For many campaigns: 5 boxes**
  *(still used to collect on Si plates; not all analyzed)*

- **SEM with EDX on Si plates with particles**

*Note:*
*- Si plate ideal for analyses*
*- boxes: no collection efficiency problem (?)*



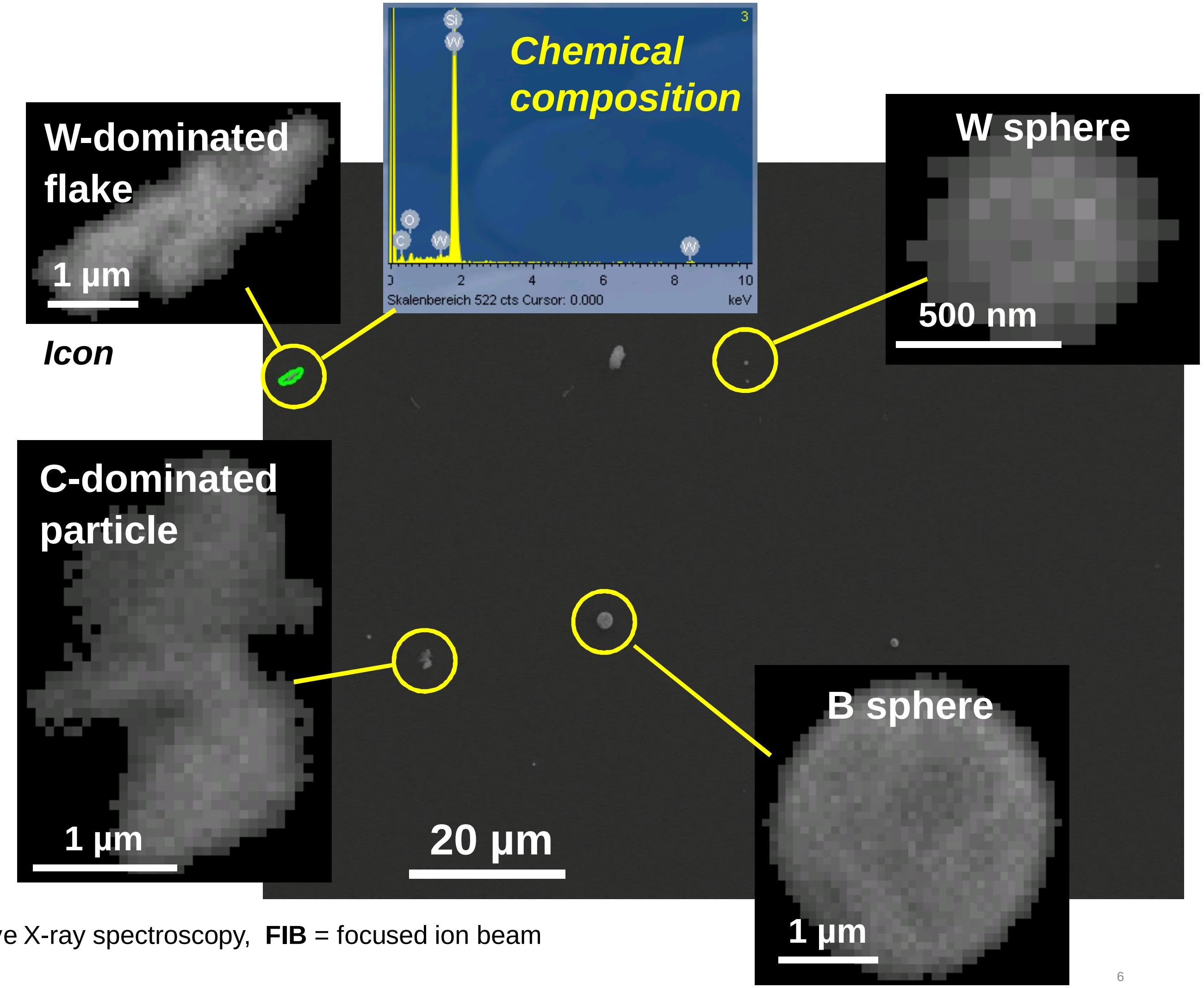

*Positions 2009 in AUG*

**SEM** = Scanning electron microscopy, **EDX** = Energy dispersive X-ray spectroscopy, **FIB** = focused ion beam

# Dust in AUG: Analysis: Individual particles

- **SEM / EDX on Si plates**
- **Measure all particles**
  **by scanning area** *(several mm²)*
- **Automated particle detection**
  → *EDX for each particle*
- **10000 particle / weekend**
  → *statistically relevant number*
  → *filtering / classification*
  *(e.g. W containing)*

- **Detail investigations on selected particles**
  - *high resolution images*
  - *inner morphology (by FIB cutting)*




**SEM** = Scanning electron microscopy, **EDX** = Energy dispersive X-ray spectroscopy, **FIB** = focused ion beam

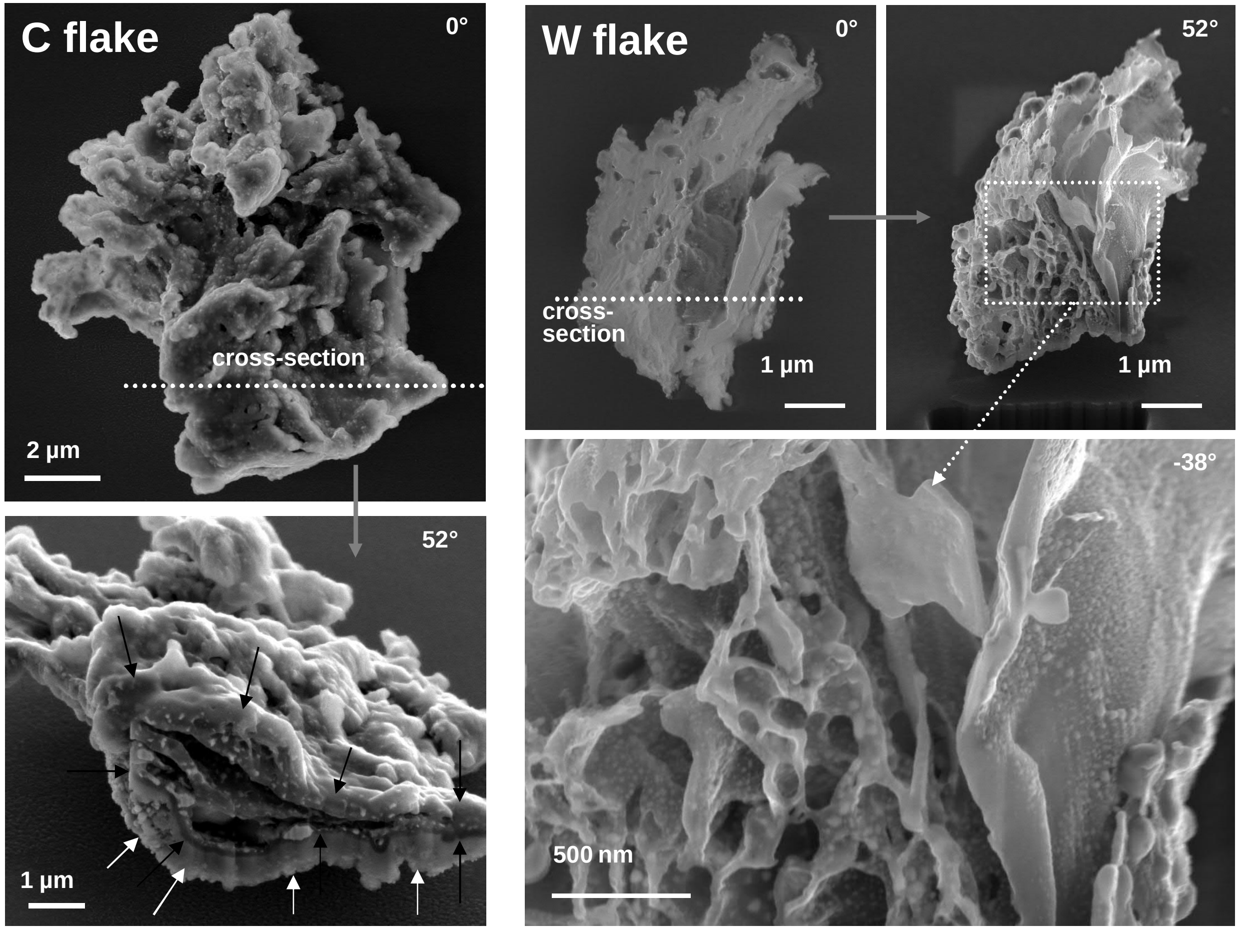
# Dust in AUG: Analysis: individual particles

- **Zoo of different particles**
- **Even fragile particle**
- **Mix of B, C, O, W**

- **Analysis of interesting particle versus typical particle**

→ **Statistical relevance due to huge data base**

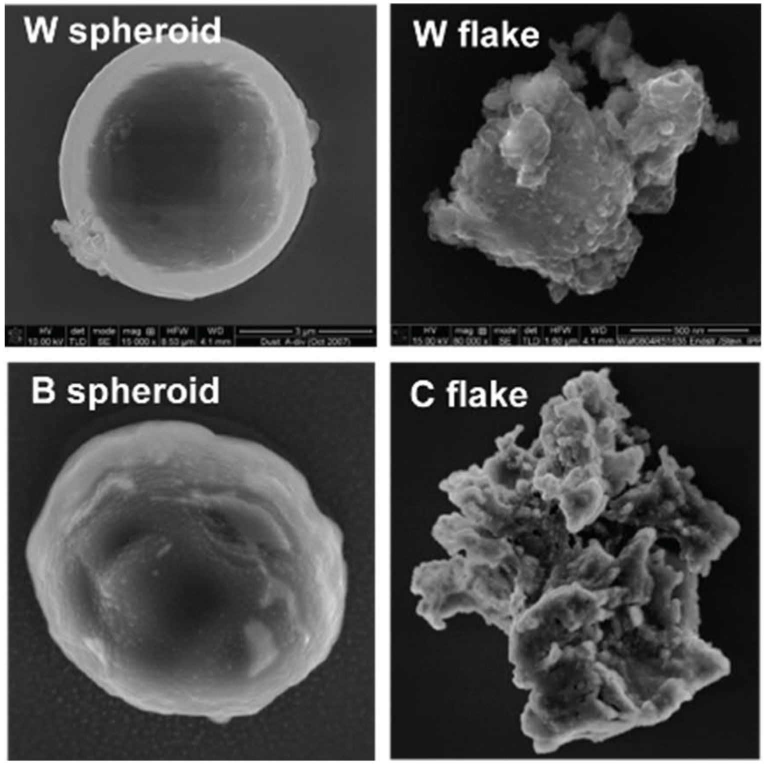
- **Detail investigations on selected particles**
  - *high resolution images*
  - *inner morphology (by FIB cutting)*




**SEM** = Scanning electron microscopy, **EDX** = Energy dispersive X-ray spectroscopy, **FIB** = focused ion beam

*[Balden et al., 2014, Nuclear Fusion 54]*

# Dust in AUG: Classification

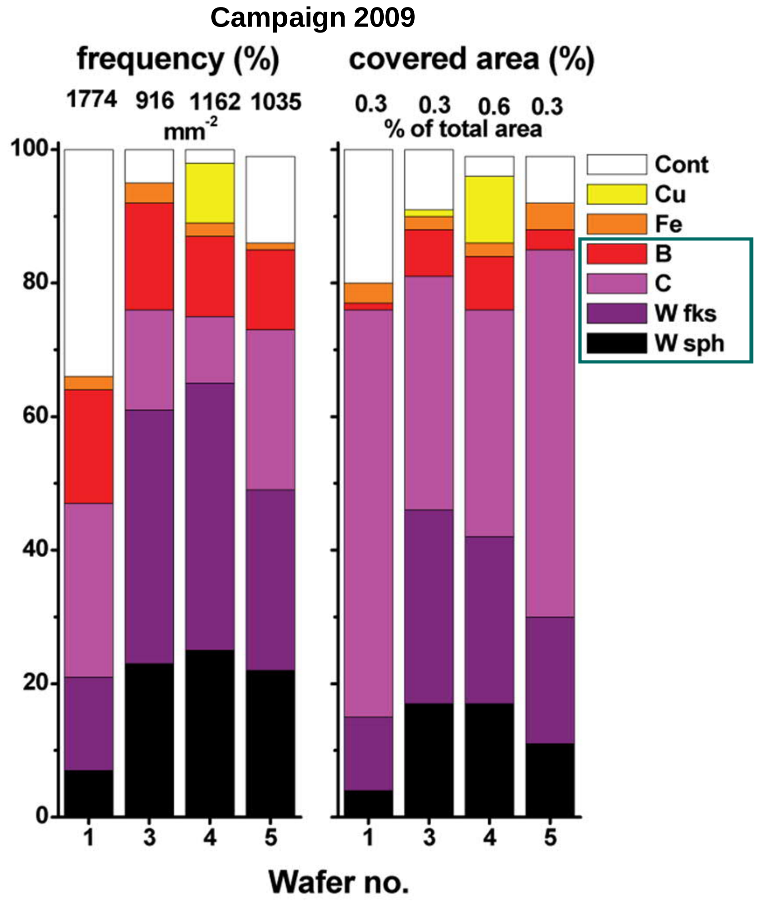



[Balden et al., 2014, Nuclear Fusion 54]

- **Si wafer technique, automated analysis of some 1000 particles**
  - *at 5 locations*
  - *over several years*

- **Classification by shape & composition**

→ **~90% of dust consist out of 4 classes**

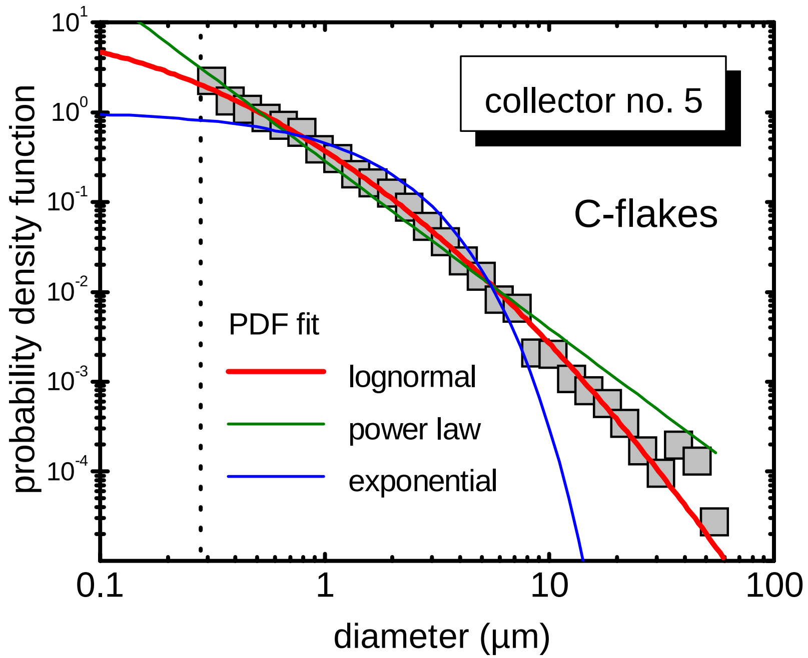


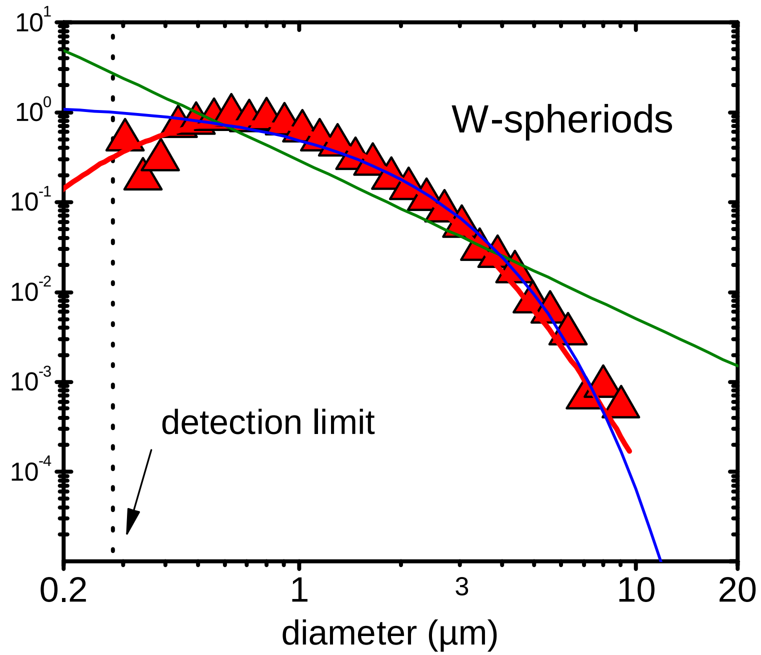

[Endstrasser et al., 2011, J. Nucl. Mater. 414]

# Dust in AUG: Distribution functions

- **Particle size distribution: Selective for shape + composition → filtering** *(statistical relevance!)*

**→ Assessment of amount**




*example of collector #5, campaign 2009*

*[Balden et al., 2014, Nuclear Fusion 54]*

# Dust in AUG: Amounts

- **Particle size distribution: Selective for shape + composition → filtering** *(statistical relevance!)*

**→ Assessment of amount**

**→ Geometrical extrapolation → 1 g / campaign in AUG**

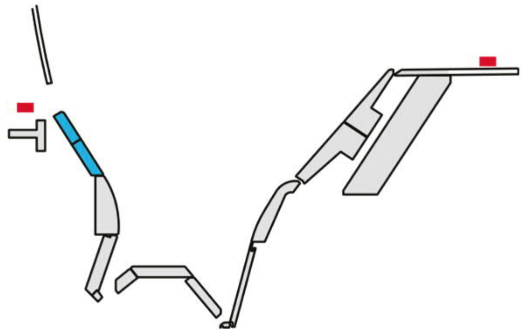
**→ 0.5 g / 400 s ITER shot**

*Would that mass be collectable e.g. by vacuum cleaning?*

| | directly from data | | | | extrapolated from lognormal fit | | | |
|---|---|---|---|---|---|---|---|---|
| | ECD of largest particle (µm) | dust volume (100 $\mu m^3/m^2$) | surface area (100 $\mu m^2/m^2$) | dust mass ($mg/m^2$) | $d_{75\%vol}$ ($d_{90\%vol}$), diameter describing 75% (90%) of the total dust volume | $R_d$, fraction of particles with diameter below $d_{min}$ | $R_{vol}$, fraction of particle volume with diameter below $d_{min}$ | dust mass ($mg/m^2$) |
| 1-W-sph | 15 | 3.8 | 5.5 | 7.4 | 4 (7) | 11% | 0.056% | 8 |
| 345-W-sph | 35 | 11.5 | 22.6 | 22.2 | 5 (8) | 1% | 0.002% | 29 |
| 1-WCB-isp | 29 | 24.6 | 43.5 | 7.4 | 29 (58) | 47% | 0.028% | 15 |
| 345-WCB-isp | 53 | 70.7 | 55.9 | 21.2 | 80 (171) | 46% | 0.006% | 37 |

*[Balden et al., 2014, Nuclear Fusion 54]*

Thickness assessment from SEM

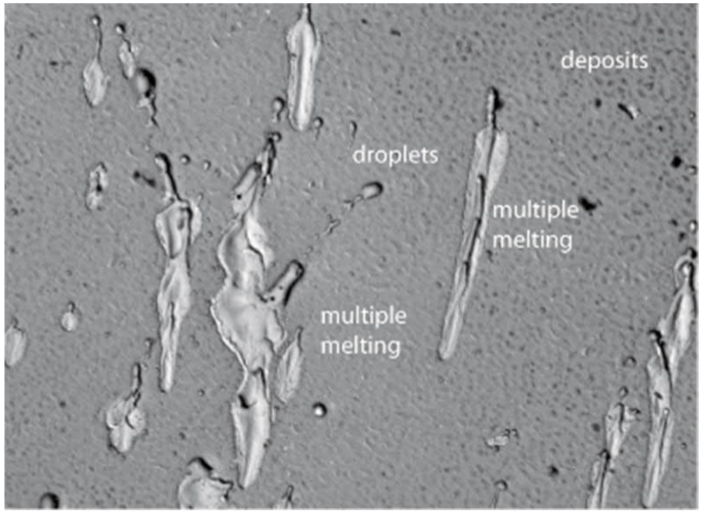


# Arcing studies in AUG

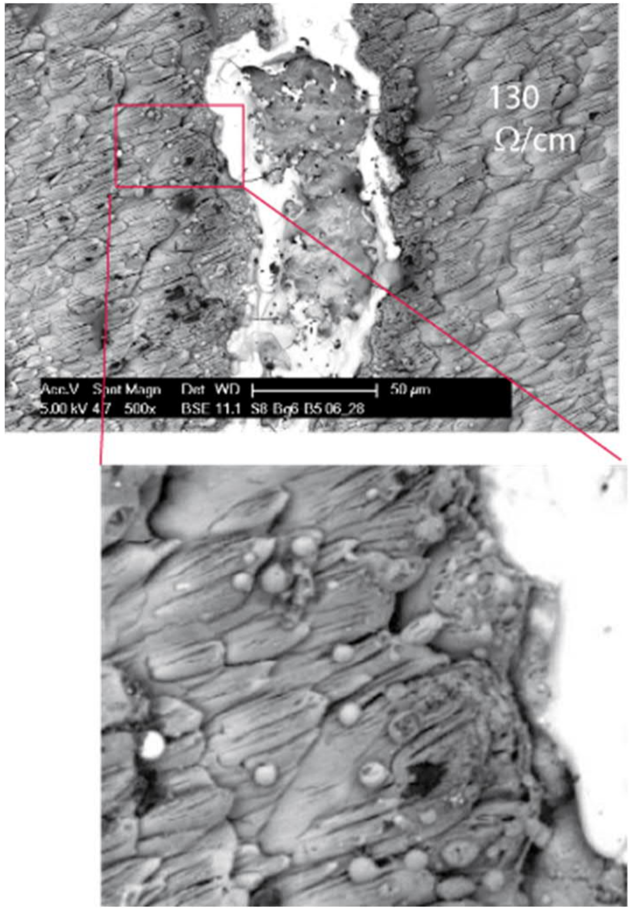
# Arcing studies in AUG: Intro

- **Arc traces found in all devices**

- **Neglected since carbon use as PFCs**




*[Rohde et al.,2021, Nucl. Mater. Energy 29]*




*[Rohde et al.,2011, J. Nucl. Mater. 415]*

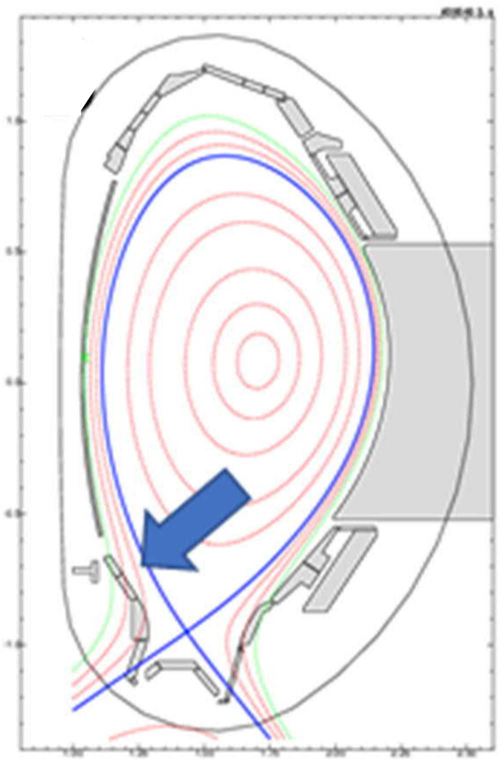
- **Arc: local plasma fed from PFC**
  - *non linear, high dynamic*
  - *melting, droplet production*

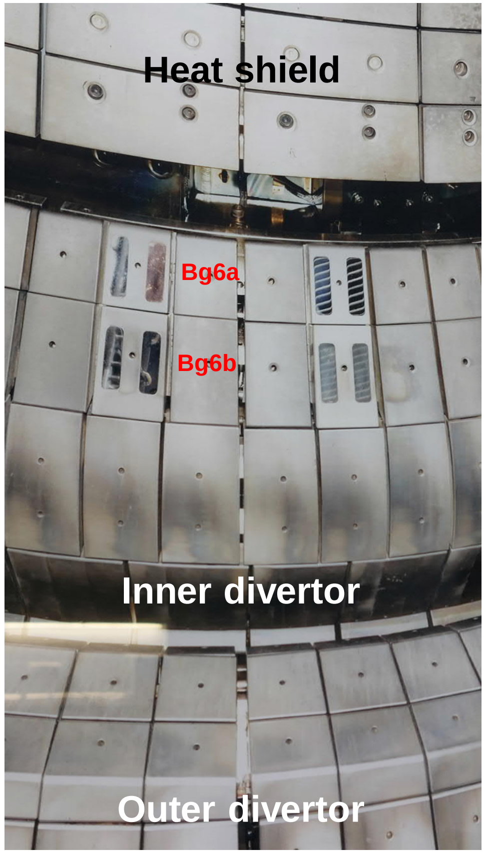
**→ W spheres found as dust in AUG**

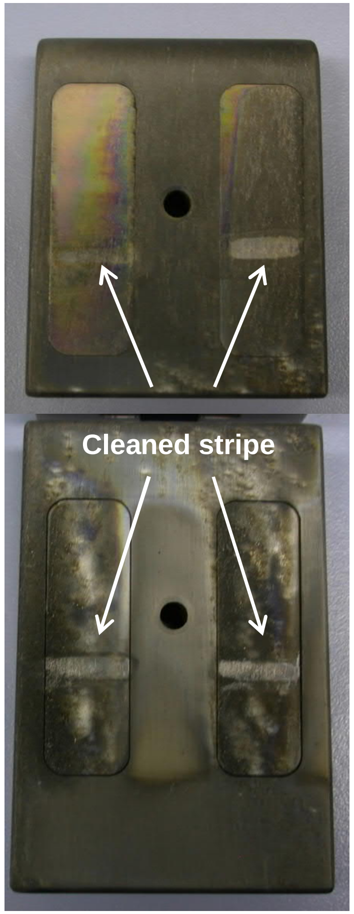
# Arcing studies in AUG: Experiment

- **Polished inserts at inner divertor baffle** *(different metals)*
- **Exposed for one entire campaign**
- **Microscopic analysis**

- **Thick deposit with arc traces**
- **Cleaned stripe for erosion measurement** *(polished metal surface)*





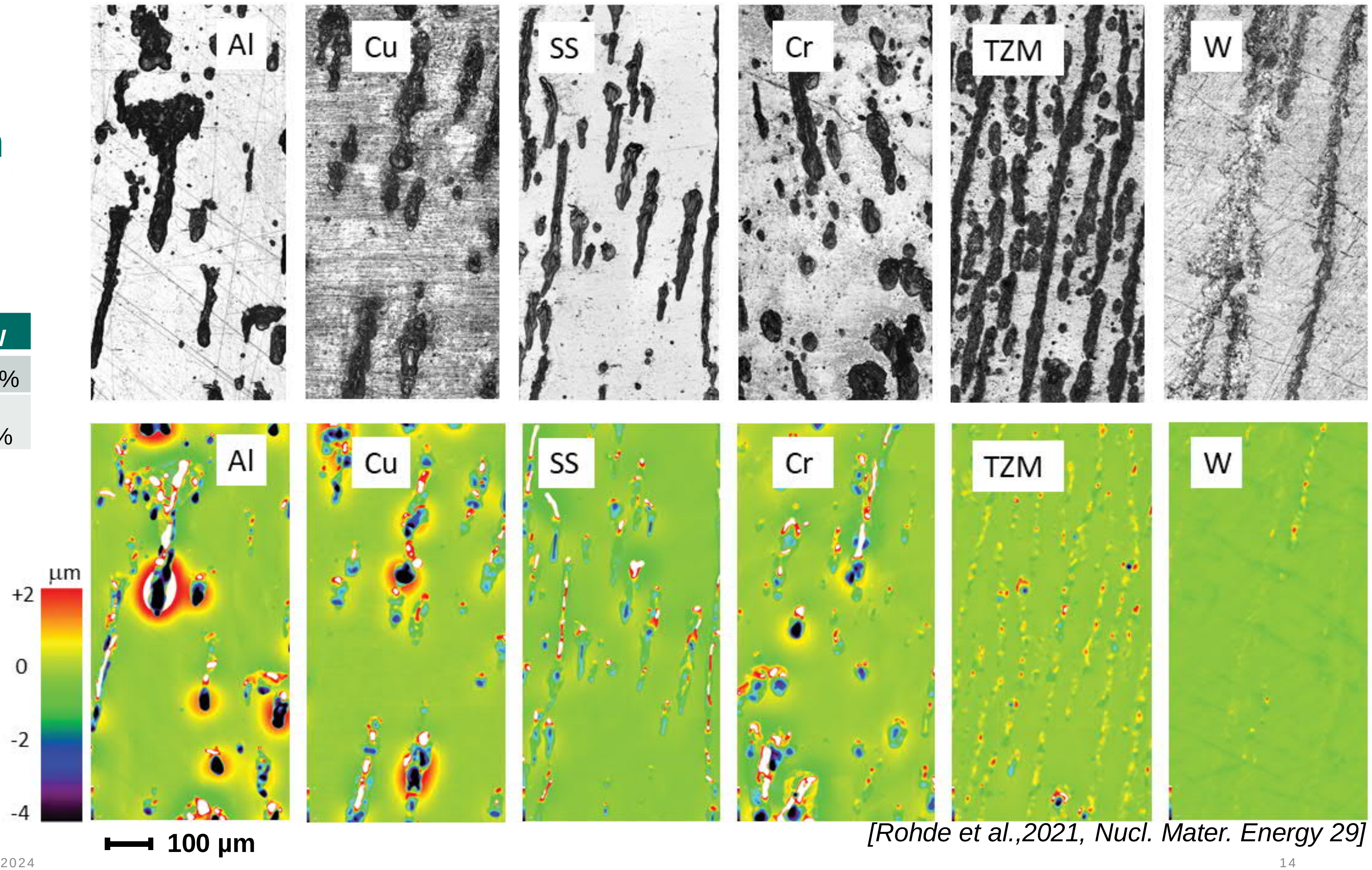



# Arcing studies in AUG: Depth maps

- Deposit cleaned away
- Not all dark structures do correspond to erosion
- Effected area different for studies metals

| | Al | Cu | SS | Cr | TZM | W |
|---|---|---|---|---|---|---|
| optical | 24% | 21% | 13% | 23% | 41% | 12% |
| erosion >0.4 µm | 14% | 13% | 7% | 8% | 10% | 5% |

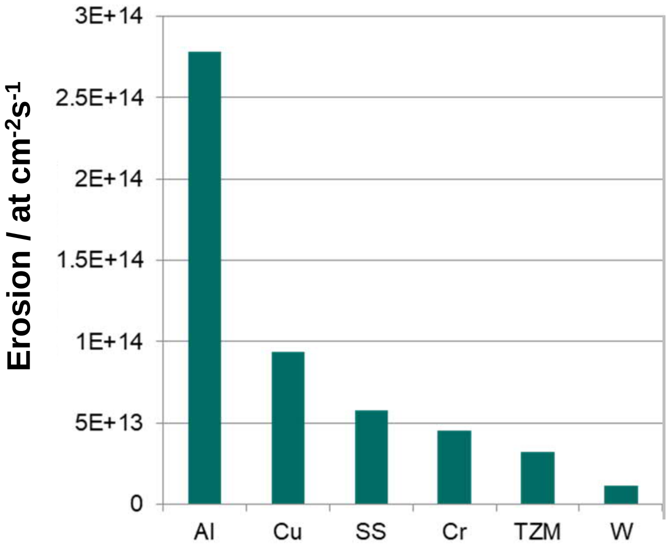
- Visible rims mostly close to deep structures
- Depth varies with metal
- W lowest erosion




[Rohde et al.,2021, Nucl. Mater. Energy 29]

# Arcing studies in AUG: Erosion

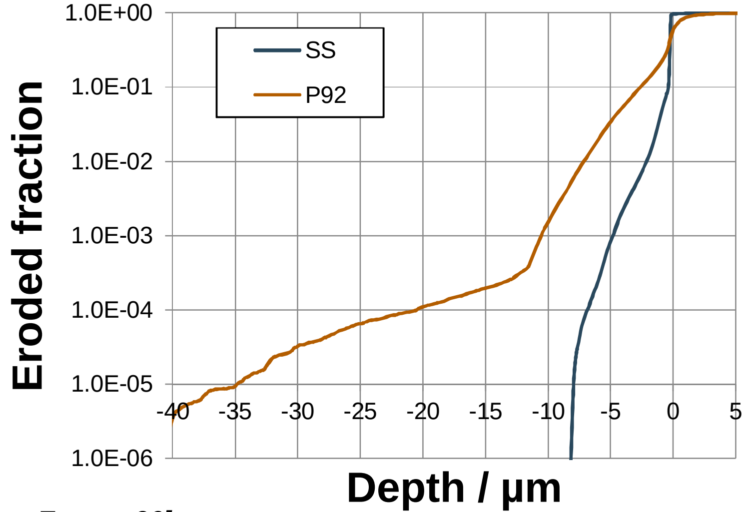
- **Erosion by arcing depends on melting temperature**
- **Arcing at AUG inner baffle region**
  - ➢ **W erosion: 1.2e13 at cm$^{-2}$ s$^{-1}$**




**Side remark**

- **Magnetic steel shows higher erosion**
- **Modification of local magnetic field**
- **Deep holes (> 0.05 mm)**

**→ More investigations needed..**




*[Rohde et al.,2021, Nucl. Mater. Energy 29]*

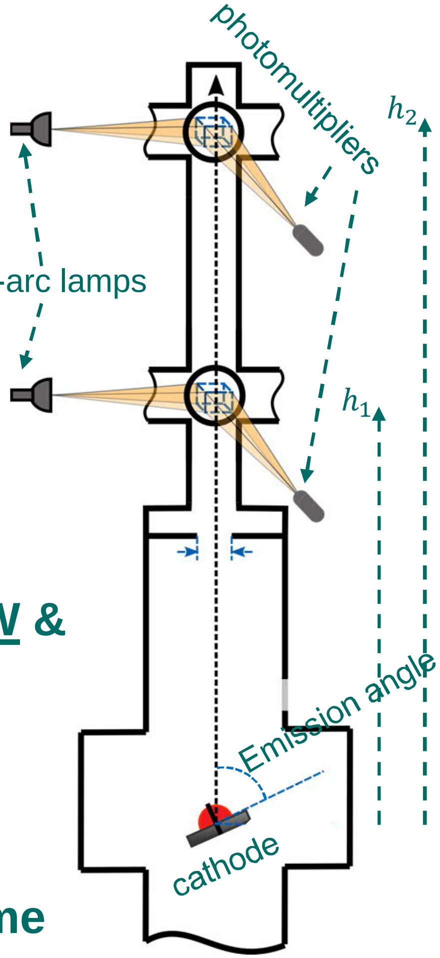
# Arcing on W in lab

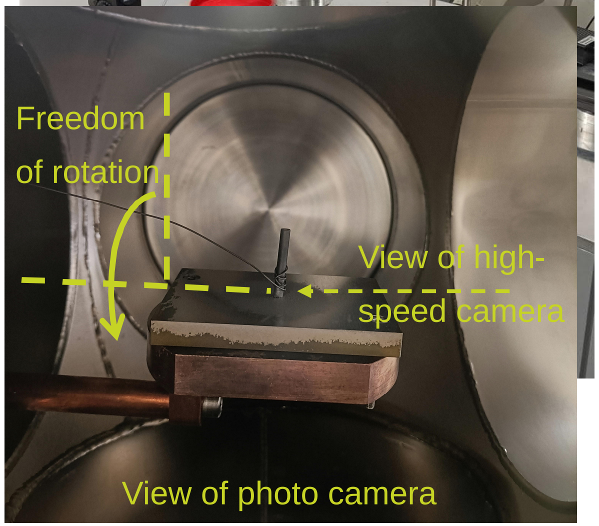
# Arcing on W in lab

<u>Topic</u>: **Distributions of size, velocity, emission angle & temperature of emitted particles and their shape (microstructure)**

**→ Input for calculations to access transport & impact on plasma**

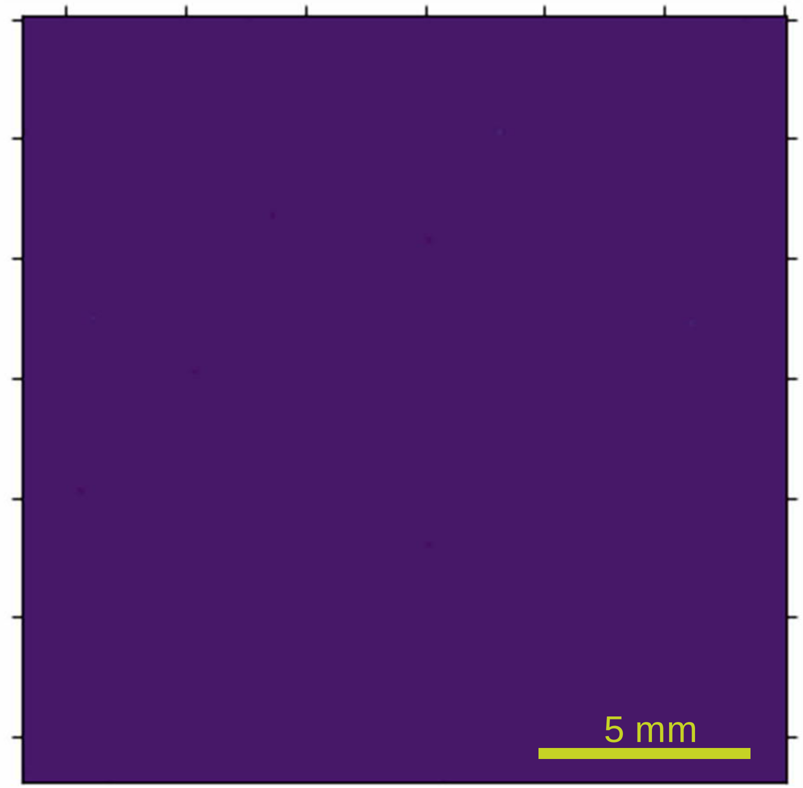
- **Devoted device to ignite & burn arcs <u>on W</u> & to detect released particles by**
  - **light scattering** (all materials)
  - **high-speed videos** (good for W)
  - **Si plates**
- **Data & videos taken and evaluated in frame of PhD thesis A. Castillo Castillo**



# High-speed video of particle emission

430 kfps => 2.3 μs per frame (1 μs exposure)




Example video of particles produced during one discharge

- **Track particle** *(Python program developed)*
- **Filtering to in focal plane**

→ **Obtain direction, speed, time trace of intensity, reconstruction of starting time/point**

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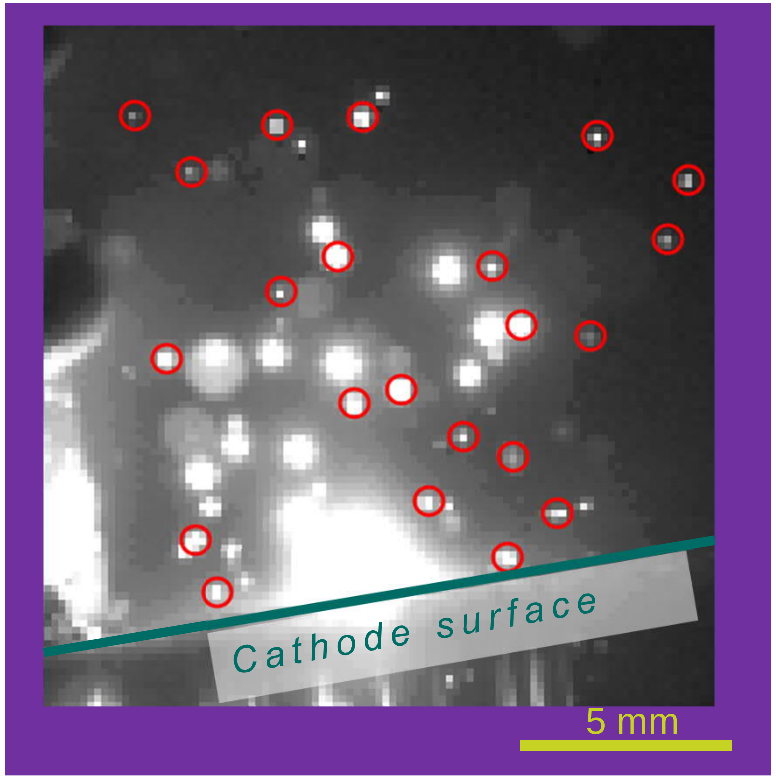


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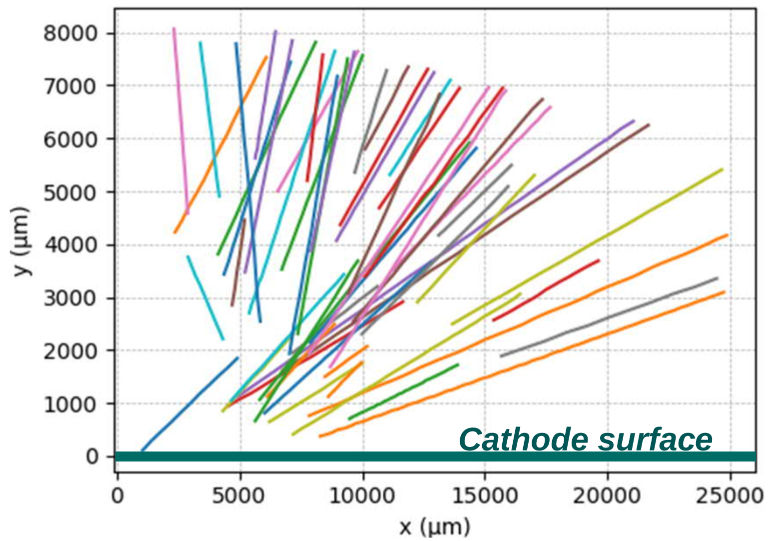

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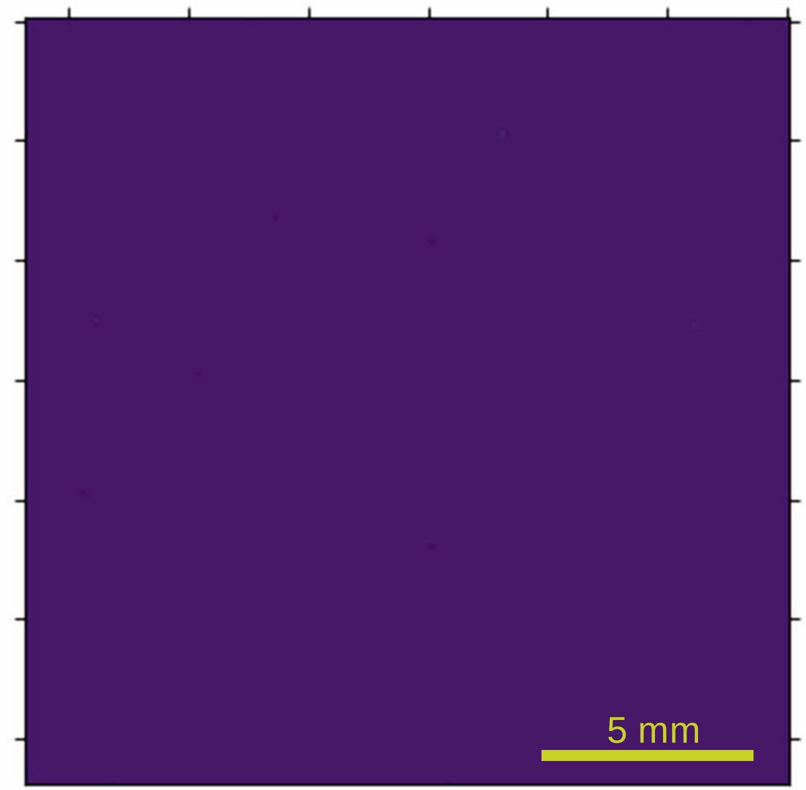



Example video of particles produced during one discharge

- **Track particle** *(Python program developed)*
- **Filtering to in focal plane**

→ **Obtain direction, speed, time trace of intensity, reconstruction of starting time/point**

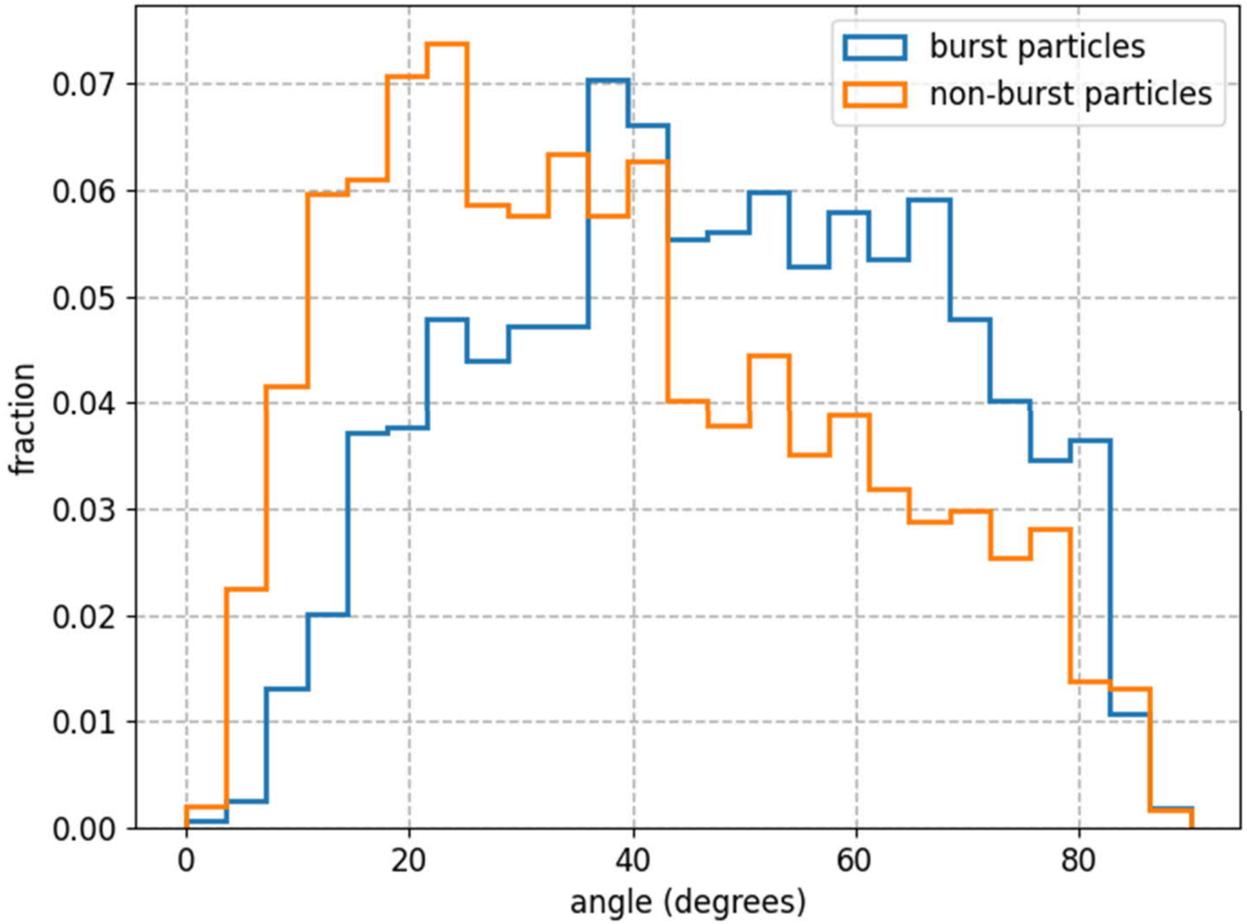
→ **Modelled time trace to separate size & temperature**

- **Particles not emitted at a constant rate: "bursts"**
  - *Increased number of particles emitted in a single event*
  - *Account for significant fraction of total particles emitted (1/3)*
  - *Source of largest particles (>3 µm) observed on video*
  - *All particles emitted by an event have similar velocities*

# Arcing on W in lab

- **Data evaluation ongoing**
- **Data sets of particles evaluated regarding different questions**

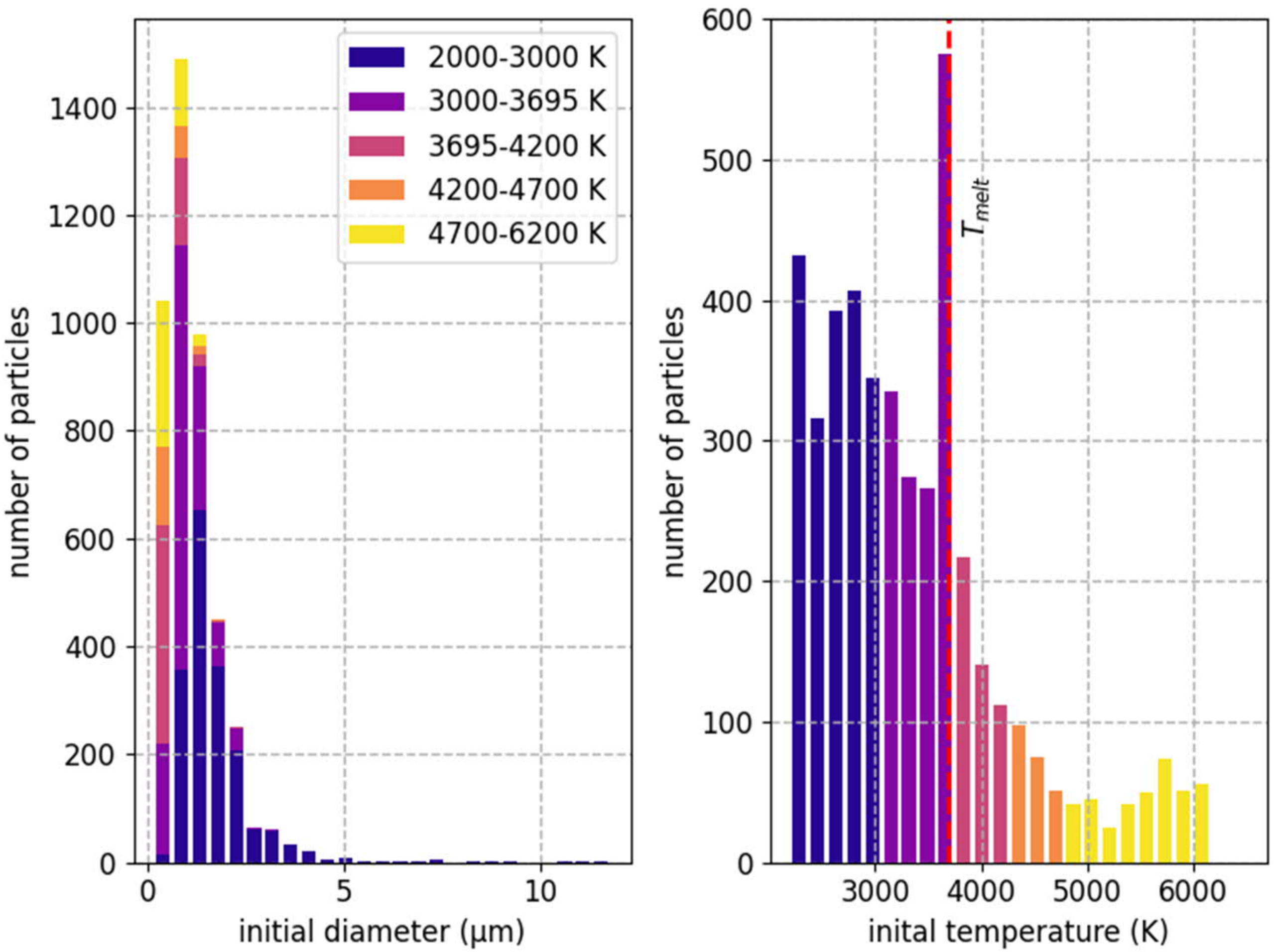
- **1st unexpected results**
  - **Bursts in emission**
    - → *other distribution angle*
    - → *other mechanisms*



# Arcing on W in lab

- **Data evaluation ongoing**
- **Data sets of particles evaluated regarding different questions**

- **1st unexpected results**
  - **Bursts in emission**
    → *other distribution angle*
    → *other mechanisms*
  - **Starting temperature**
    → *also below melting temperature!*



# Summary / Capabilities

- **Collection & analyses strategy developed** *(and assessable)*
- **Classification of dust due to large data base**
  → ***Size distributions resolved by shape & composition allow prediction of amounts***
- **Production mechanisms**
  **- Flaking off of deposits** *(by layer stress, thermo-mechanical stresses, arcing, …)*
  **- Melt events** *(by arcing, VDEs, misalignment, hot optical spots, cracking with degradation of thermal properties …)*
  **…**

→ **Judge of risk for various dust classes** *(T inventory, radio nucleotides, chemical activity, …)*

- **Erosion (of W) by arcing determined in AUG**
- **Particle emission by arcing studied** *(distribution of size, temperature, emission angle, …)*

*Side remark: Fuel retention only very sparsely measured (in individual particles)*
*→ more (particle-resolved) studies needed for risk assessment*

# Thank you for your attention !