EUROfusion

# SP B.1 ENEA activity in 2021-2022: Overview of GyM results

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Beneficiary: ENEA
Linked Third Parties: ISTP-CNR Milano and Politecnico di Milano

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# Overview of GyM results

*PWIE.SPB.1.T002.D002*
Role of roughness in sputtering process of W by GyM He plasma

Focus of this talk

Linked PWIE-SPs

**Sample production**

*PWIE-SP B.4.T-T002-D001*
W-based coatings with pre-defined properties (incl. SEM, AFM, TDS characterisation) produced for analyses and plasma experiments

**Modelling**

*PWIE-SP D.1.T-T002-D003*
Plasma background parameters of GyM for modelling of impurity migration experiments
*PWIE-SP D.3.T-T002-D002*
ERO2.0 simulations of dynamic morphology studies in GyM, ERO2.0 simulations of the transport of sputtered material in GyM, Global ERO2.0 modelling of erosion/deposition in AUG

Highlight talk G. Alberti

*All activities carried out in Milan in frame of collaboration between ISTP-CNR and Polimi*

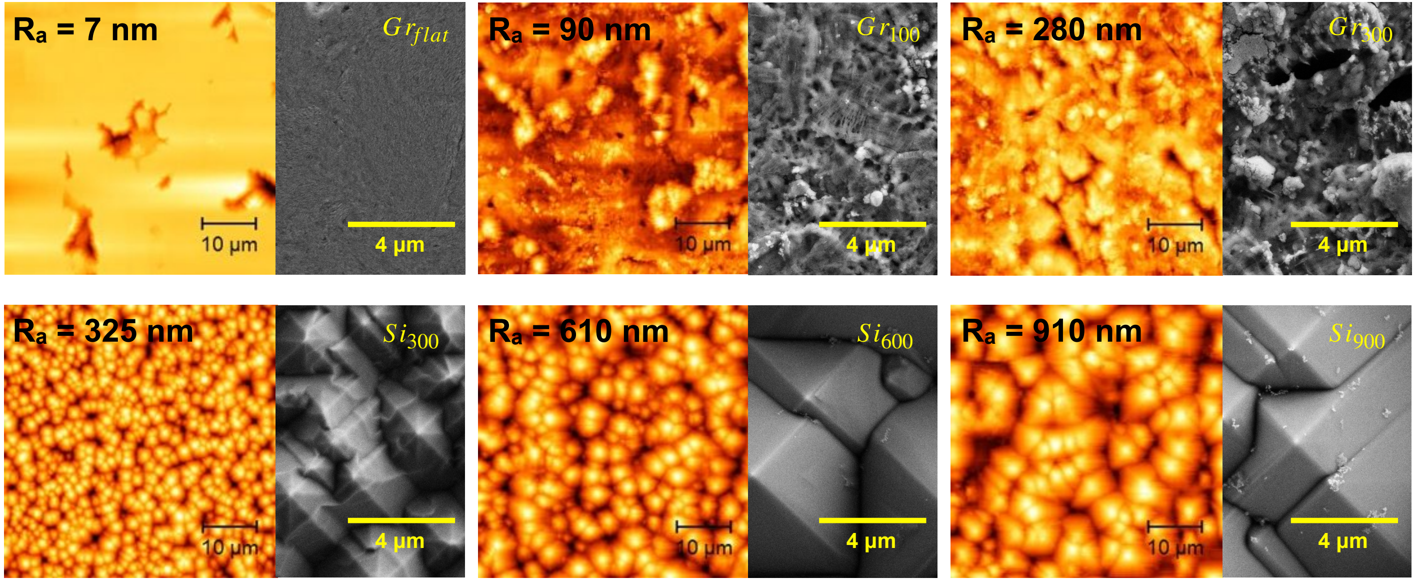
# Samples production and characterisation

**W coatings** on top of **graphite** and **Si** substrates, from SP B.4 + **polished bulk W** ($R_a$ ~10 nm)

## Substrates (ISTP)

- Polished **graphite**
- Rough **graphite** substrates by plasma etching $R_a \rightarrow$ 100, 300 nm

- Flat **Si**, $R_a$<1 nm
- **Si** with pyramids by chemical etching $R_a \rightarrow$ 300, 600, 900 nm




**8 kinds of samples**

# Samples production and characterisation

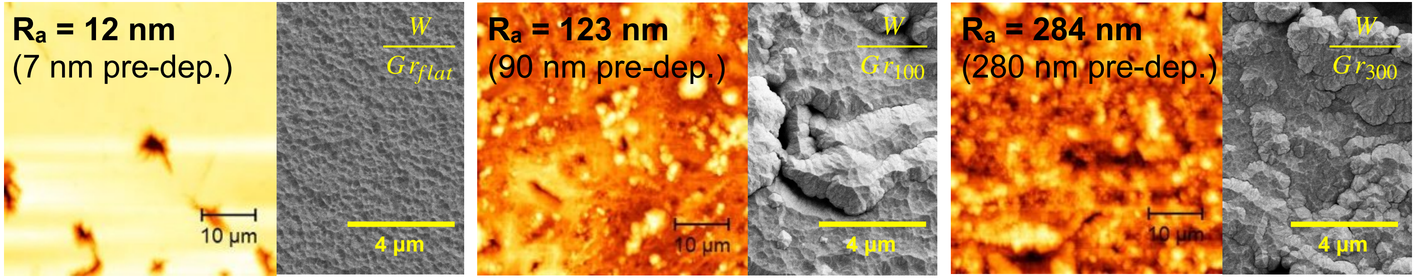
**W coatings** on top of **graphite** and **Si** substrates, from SP B.4 + **polished bulk W** ($R_a$ ~10 nm)

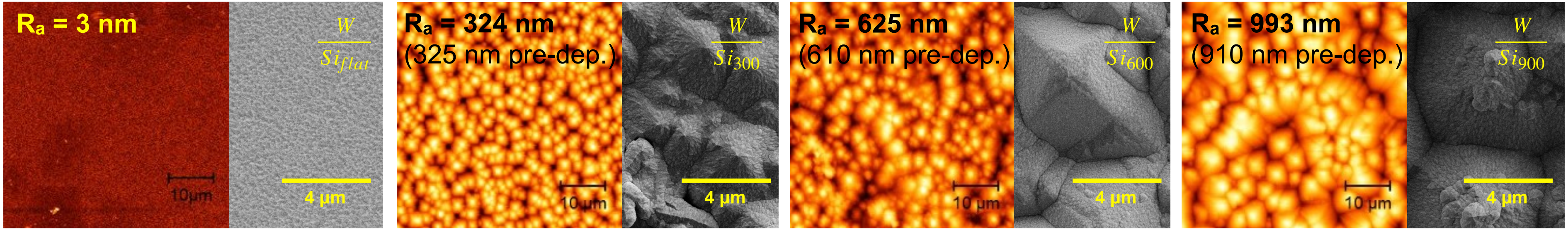
**Substrates (ISTP)**

**+**

**500 nm compact W film**

**by HiPIMS (Polimi)**




Side activity: *Study angular distribution of sputtered W particles from W/Si with Catcher-QCM setup of ÖAW* (C. Cupak SP B highlight talk, 17/10/22)

# Samples production and characterisation

W coatings on top of **graphite** and **Si** substrates, from SP B.4 + **polished bulk W** ($R_a$ ~10 nm)

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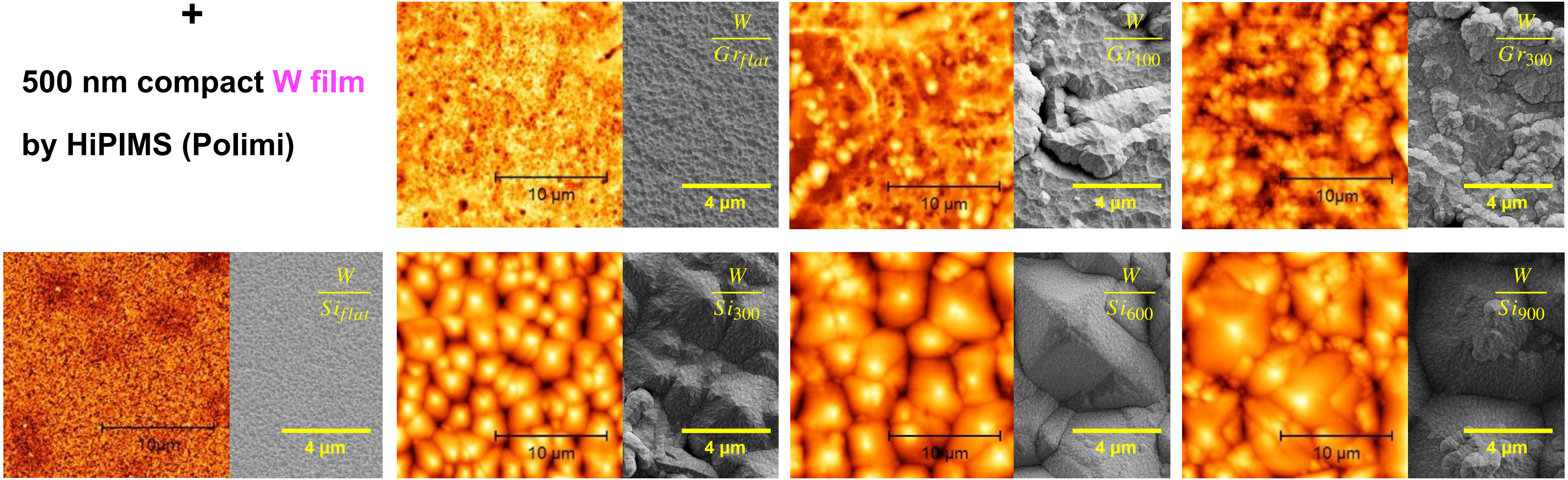



AFM images: **20x20 µm²** → ERO2.0 input to study erosion during plasma exposure

Polimi+ISTP activity for SP D.3 (see G. Alberti SP D highlight talk, 19/10/22)

# Role of roughness in sputtering process of W by GyM He plasma

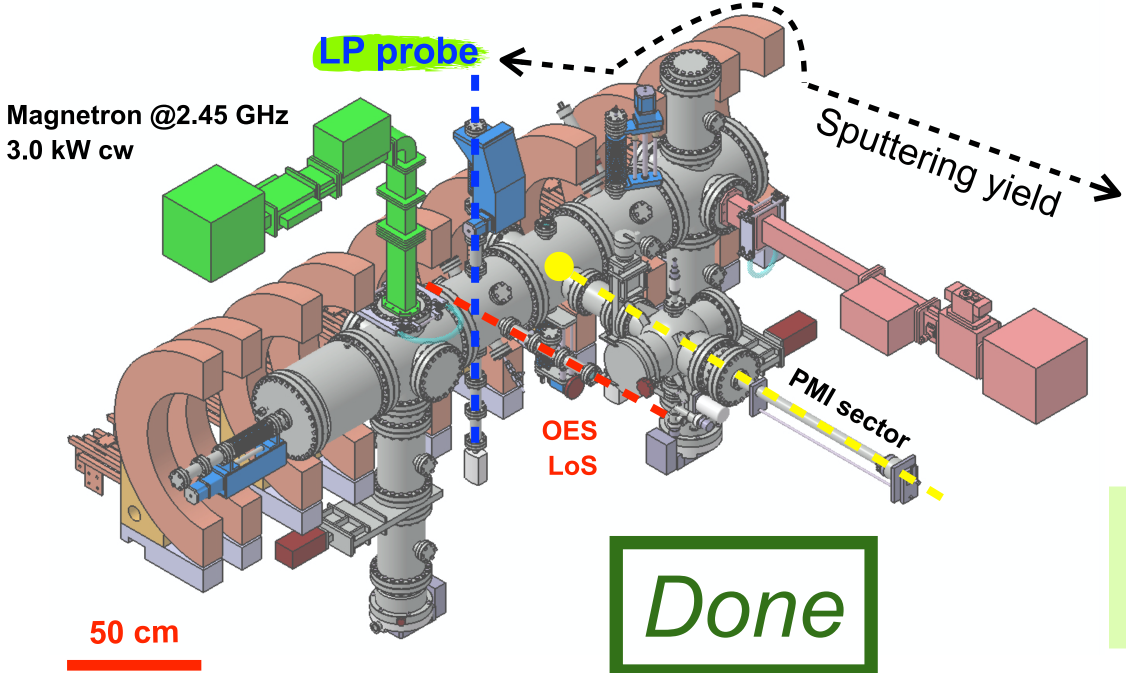
## Exposure of W/Si samples: **6** He$^+$ energies @ 4.0e24 He$^+$ m$^{-2}$

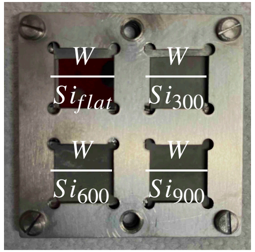
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **He$^+$ energy [eV]** | 30 | 80 | 150 | 200 | 250 | + | 350 |

NEW

Sputtering $E_{th}$ of $W_{bulk}$ by He$^+$ ~110 eV

[W. Eckstein, et al., IPP 9/82 Sputtering data]




1 cm

$T_{holder}$ ≲ 150°C

**Done**

## Before and after exposures

- **Weighing** → erosion by using balance @ CNR-Mi
- **AFM** → topography evolution @ ISTP
- **SEM** → morphology evolution @ Polimi

Data for benchmarking with SOLPS-ITER and ERO2.0 modelling efforts Polimi+ISTP SP D.1 & D.3

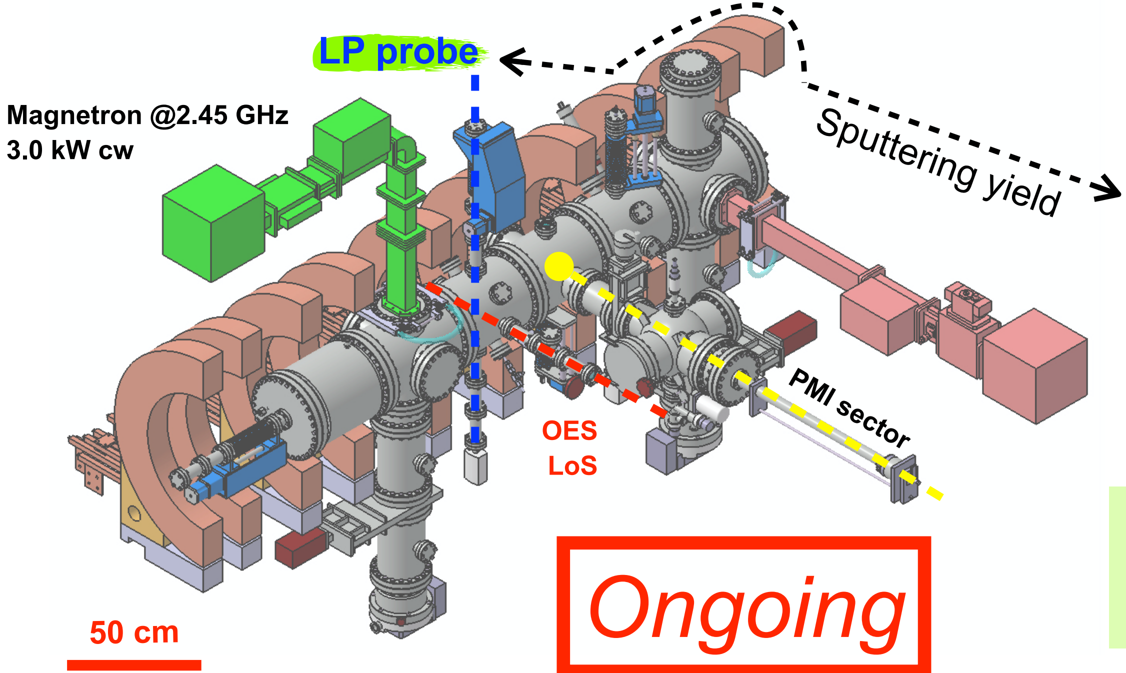
# Role of roughness in sputtering process of W by GyM He plasma

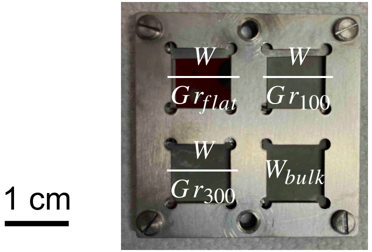
## Exposure of W/Gr + $W_{bulk}$ samples: 5 $He^+$ energies @ 4.0e24 $He^+$ $m^{-2}$

| $He^+$ energy [eV] | 30 | 80 | 150 | 200 | 250 |
|---|---|---|---|---|---|

Sputtering $E_{th}$ of $W_{bulk}$ by $He^+$ ~110 eV

[W. Eckstein, et al., IPP 9/82 Sputtering data]




**Ongoing**

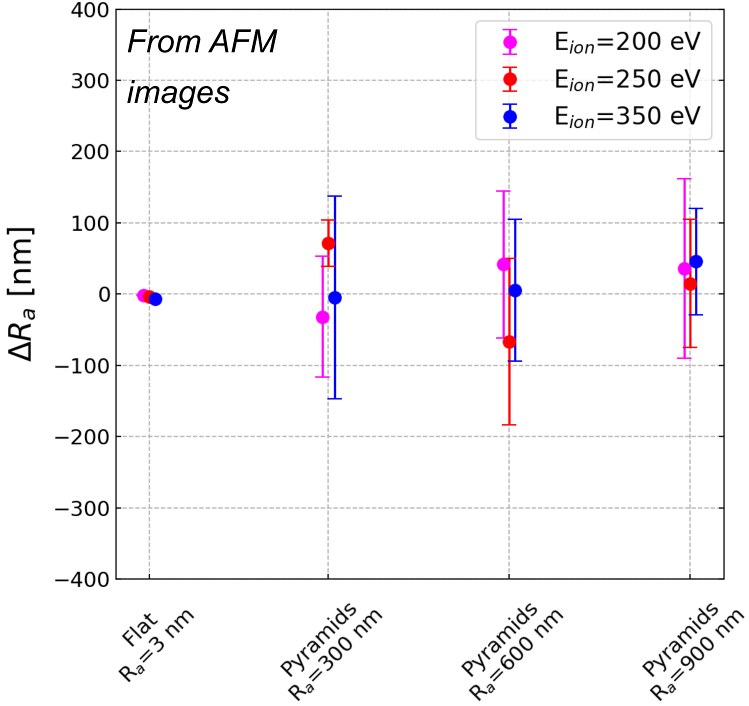
### Before and after exposures

- Weighing → erosion by using balance @ CNR-Mi
- AFM → topography evolution @ ISTP
- SEM → morphology evolution @ Polimi
- FIB marking → $W_{bulk}$ → erosion @ FZJ

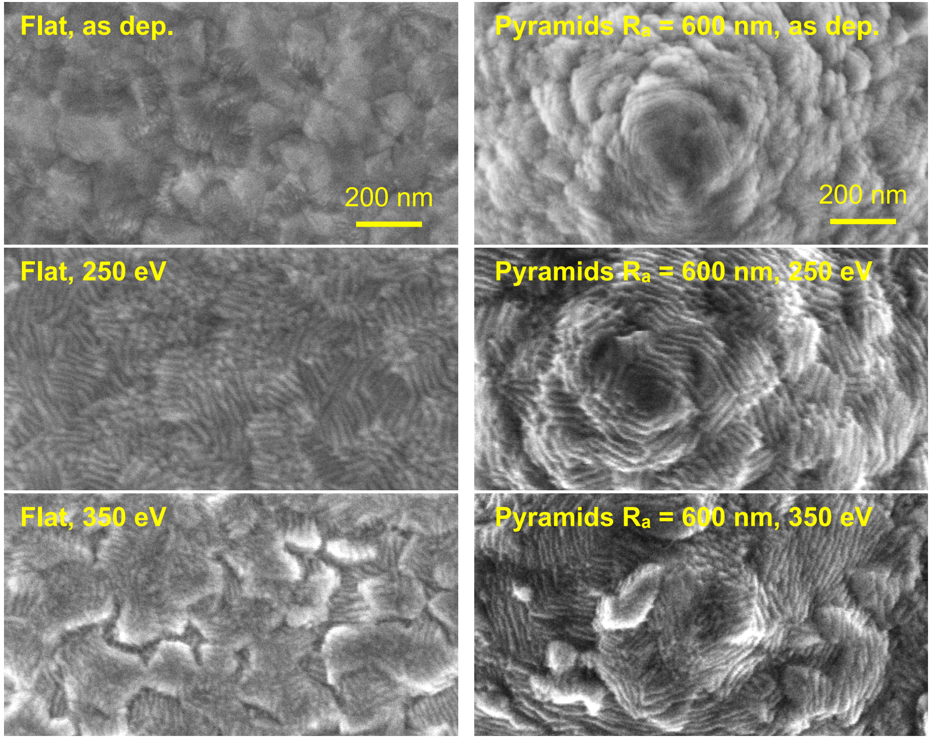
Data for benchmarking with SOLPS-ITER and ERO2.0 modelling efforts Polimi+ISTP SP D.1 & D.3

# Role of roughness in sputtering process of W by GyM He plasma

Samples topography did not significantly change after exposures

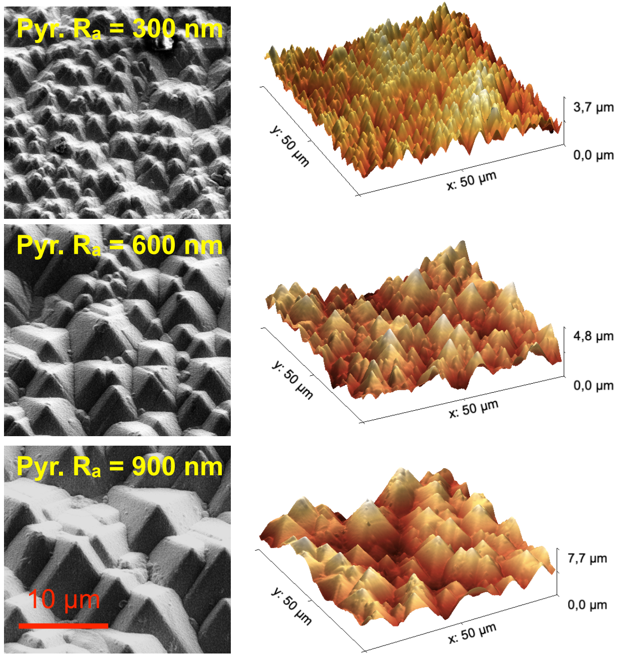


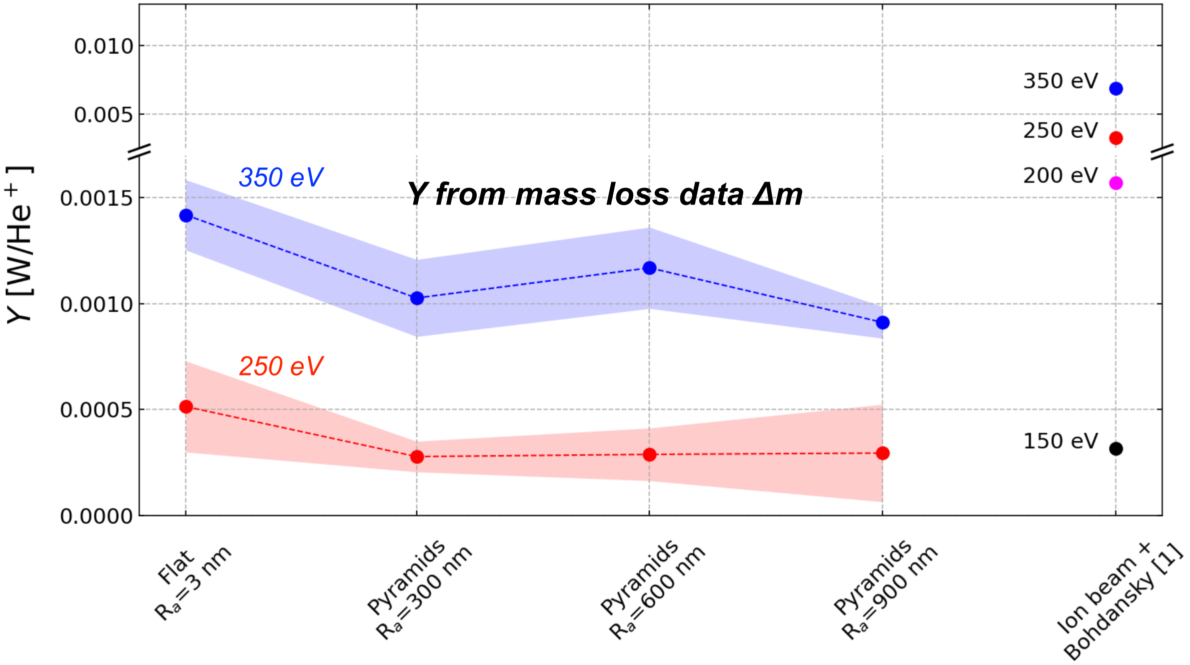

All types of W/Si: ripple nanostructures for $E_{ion} \geq 250$ eV




No significant topography and morphology modifications → determination of quasi-static sputtering yield *Y*

# Role of roughness in sputtering process of W by GyM He plasma




- No erosion for $E_{ion} \leq 200$ eV
- For $E_{ion} \geq 250$ eV → $Y_{Flat,\Delta m} > Y_{Pyramids,\Delta m}$
- $Y_{\Delta m} \ll Y_{Ion}$ → similar to what was observed in other LPD experiments [2]. In [2], It was speculated that He atoms on surface, due to He incoming flux, shield W lattice atoms reducing their sputtering probability

[1] W. Eckstein, et al., IPP 9/82 Sputtering data
[2] R. P. Doerner, Scr. Mater. 143 (2018) 137-141

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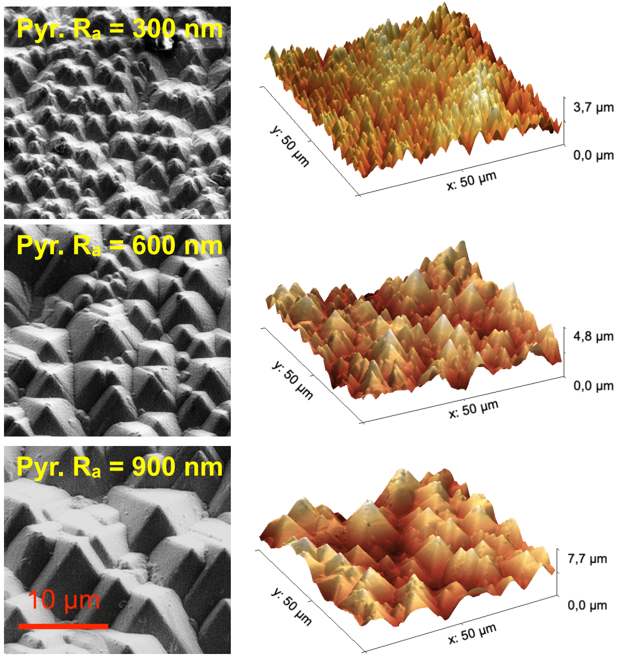


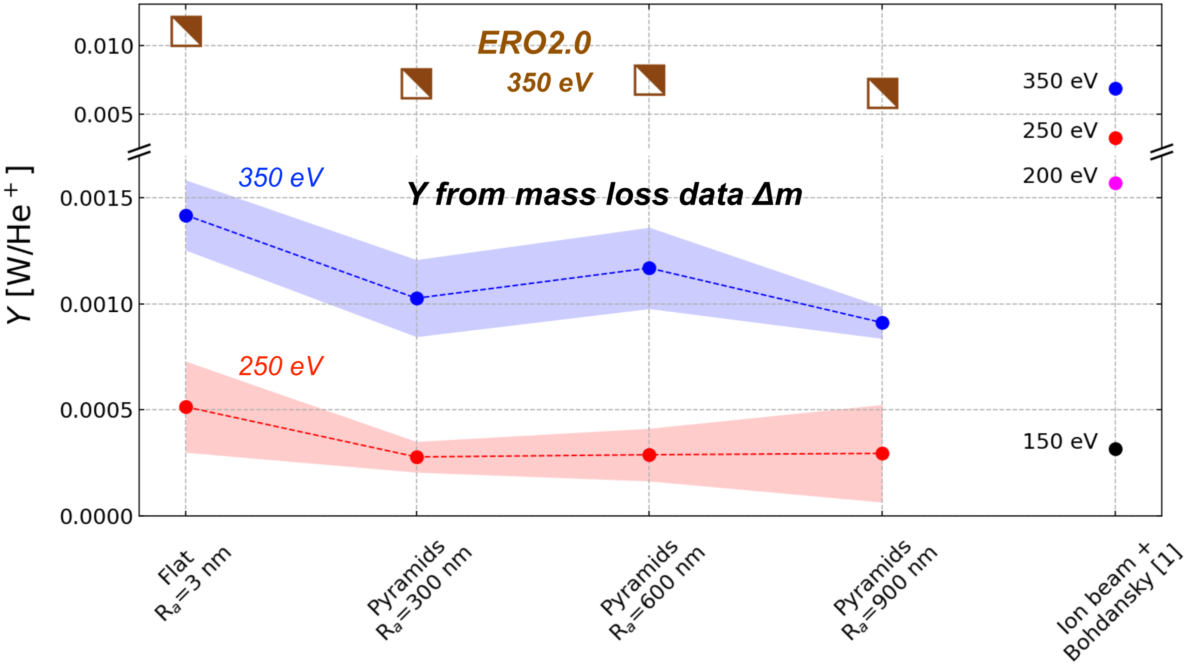


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  - This potentially explains → $Y_{\Delta m} \ll Y_{ERO}$ at 350 eV since sputtering yields as input to ERO2.0 refer to pure W surface


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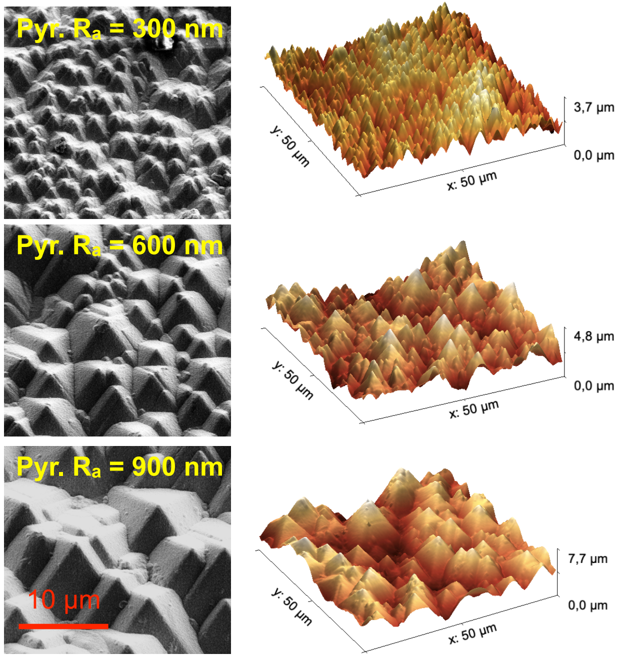


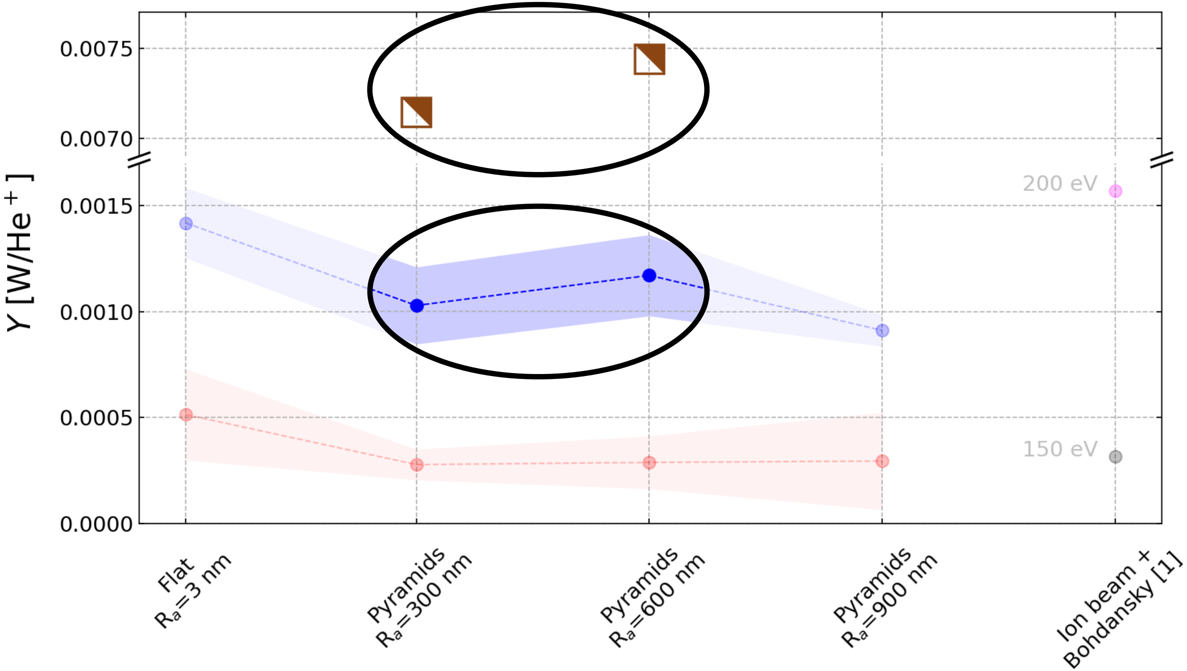


- Non-monotonous behaviour of $Y_{\Delta m}$ and $Y_{ERO}$ at $E_{ion}$ = 350 eV if $R_a$ is used for characterising surfaces
- What happen if surfaces characterised by mean value of surface inclination angle distribution, $\delta_m$, as suggested in [2]?


[1] W. Eckstein, et al., IPP 9/82 Sputtering data
[2] C. Cupak, et al., Appl. Surf. Sci. 570 (2021) 151204

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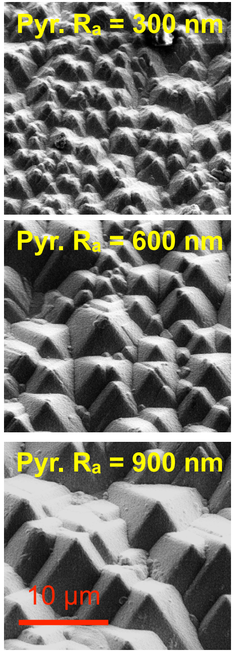


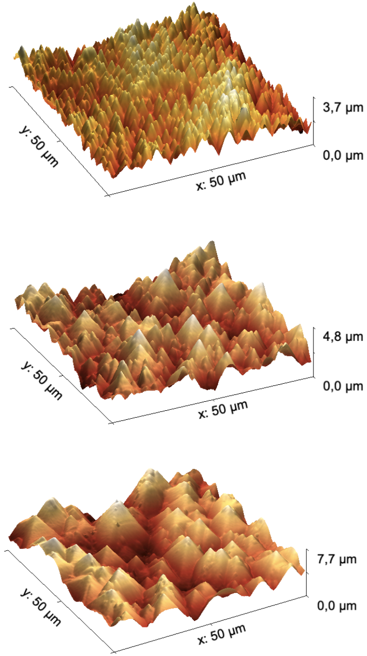


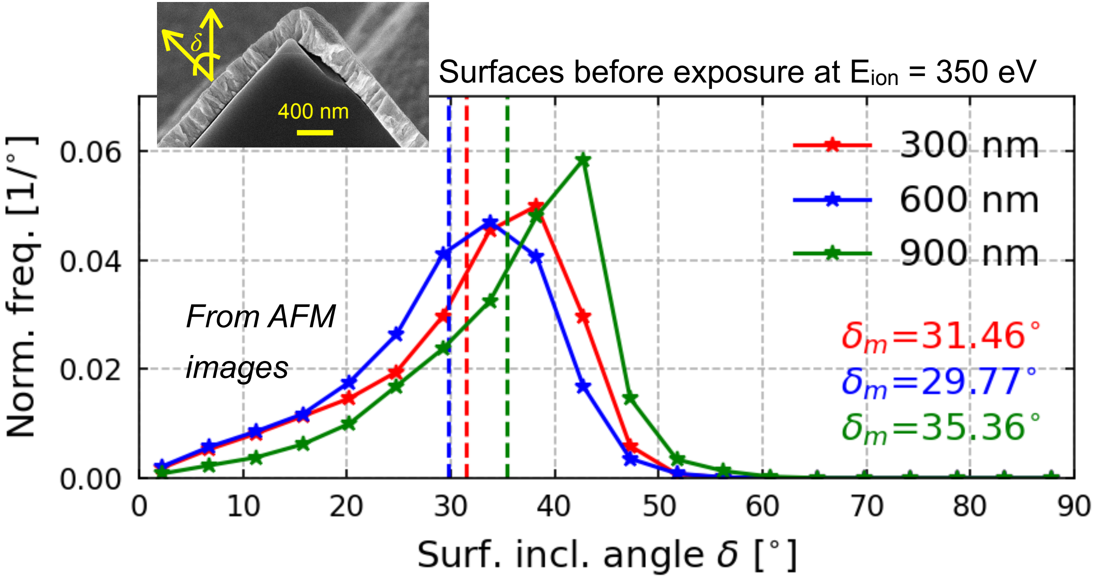


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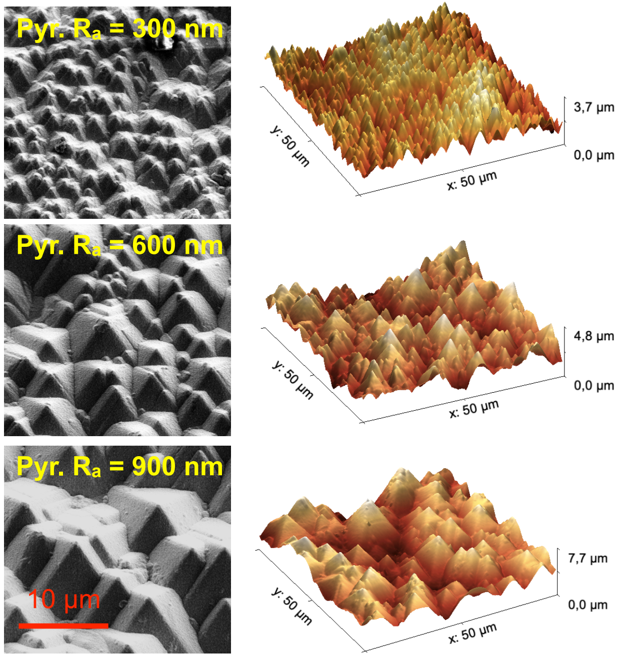


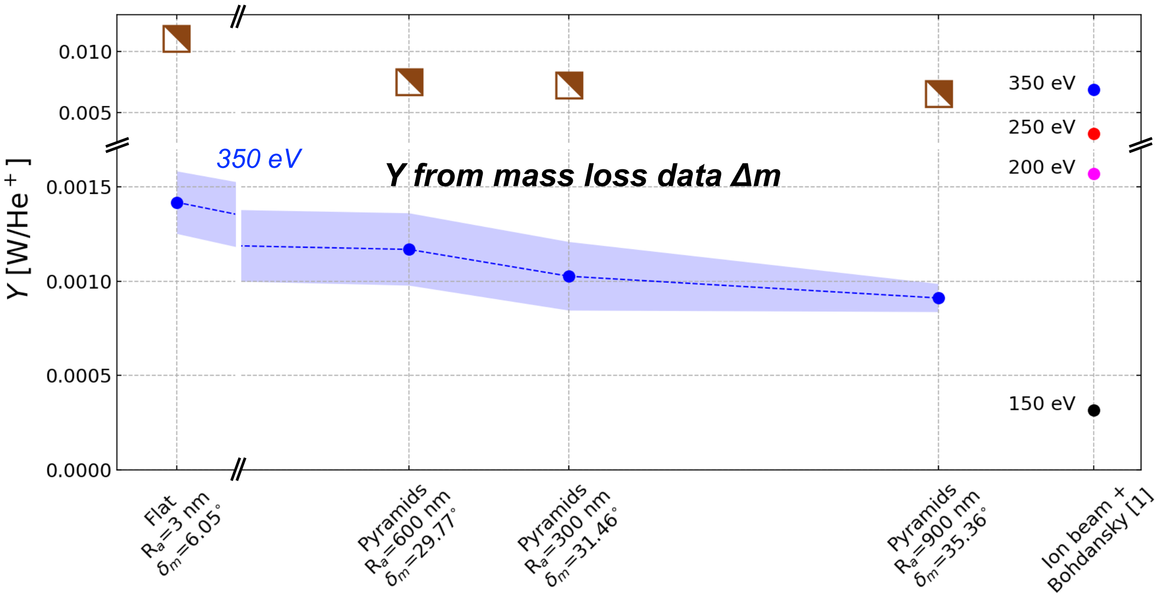


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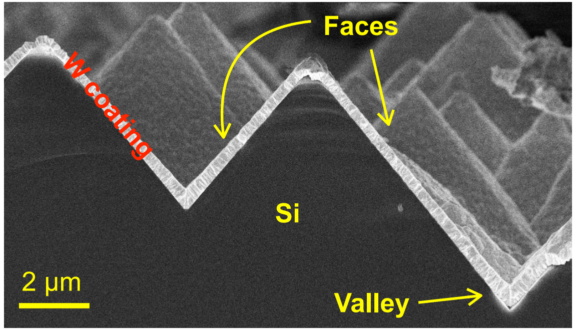
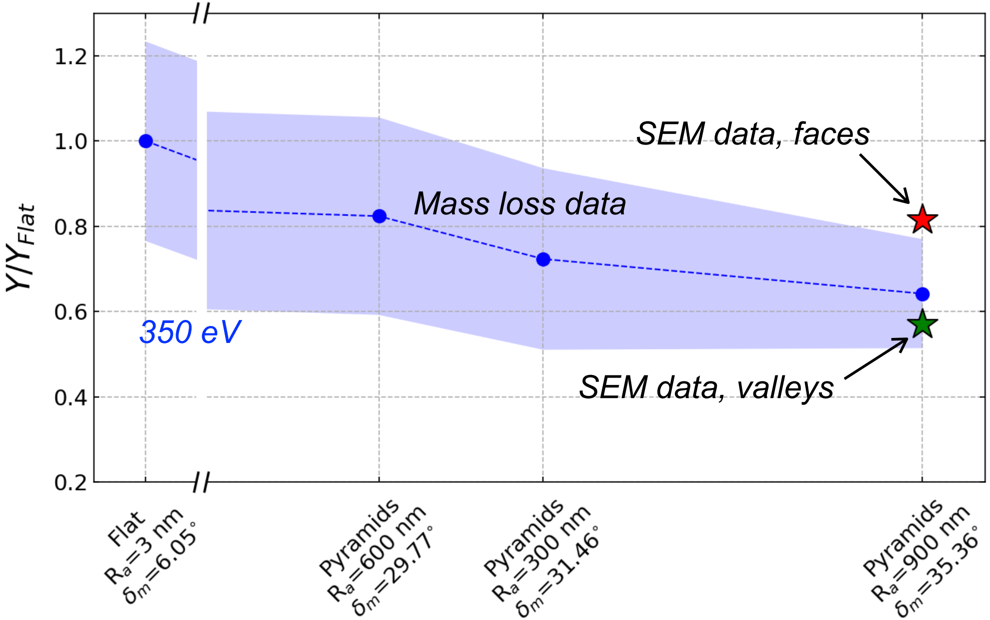
Erosion data also from SEM cs images: statistical analysis of W coating thickness loss ($\Delta s$)



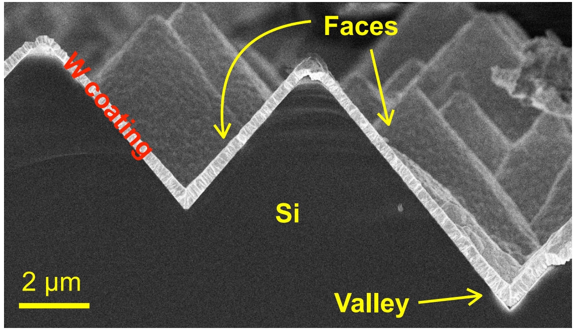

**Preliminary results**

| 350 eV | Flat | Pyr. $R_a$ = 900 nm | |
|---|---|---|---|
| | | Faces | Valleys |
| $\overline{\Delta s}\ [nm]$ | 60.7 | 49.4 | 34.6 |
| $\sigma_{\Delta s}\ [nm]$ | 17.0 | 29.9 | 35.9 |

- $\Delta s_{Flat} > \Delta s_{Pyramids}$, in agreement with $\Delta m$ data
- $\Delta s_{Pyr.,Faces} > \Delta s_{Pyr.,Valleys}$ → deposition of sputtered particles from faces in valleys?
- Further work needed to reduce $\sigma_{\Delta s}$

# Role of roughness in sputtering process of W by GyM He plasma

Erosion data also from SEM cs images: statistical analysis of W coating thickness loss ($\Delta s$)

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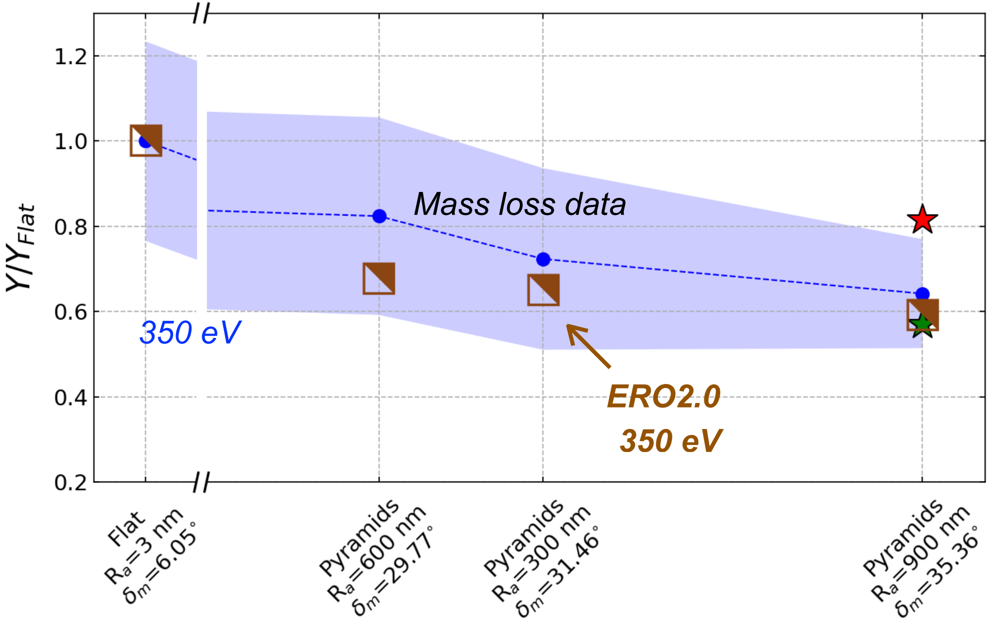



- $Y_{Pyr.}/Y_{Flat}$ from **ERO2.0**, **mass** and **thickness** loss measurements are consistent
- **Calibration** of sputtering yields as input to **ERO2.0** with $Y_{Flat,\Delta m}$ to quantitatively catch $Y_{Pyr.,\Delta m}$?

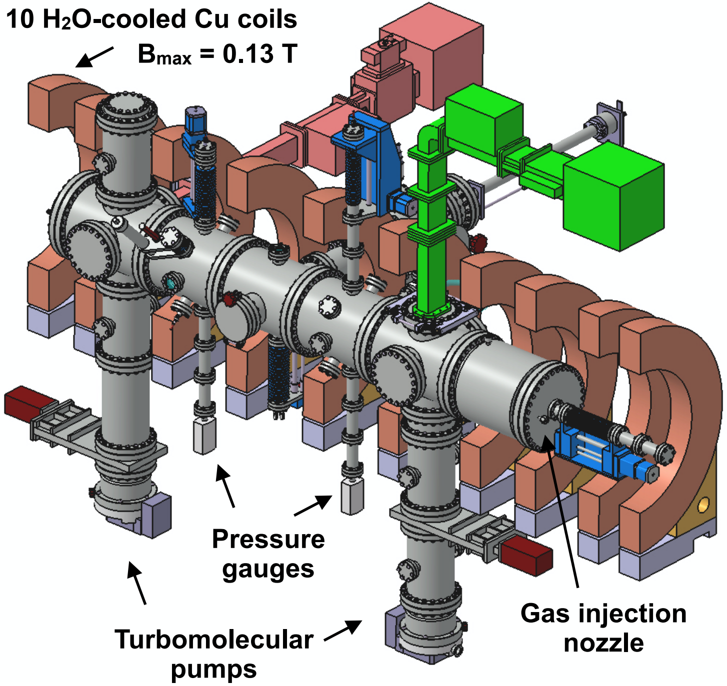
# Conclusions

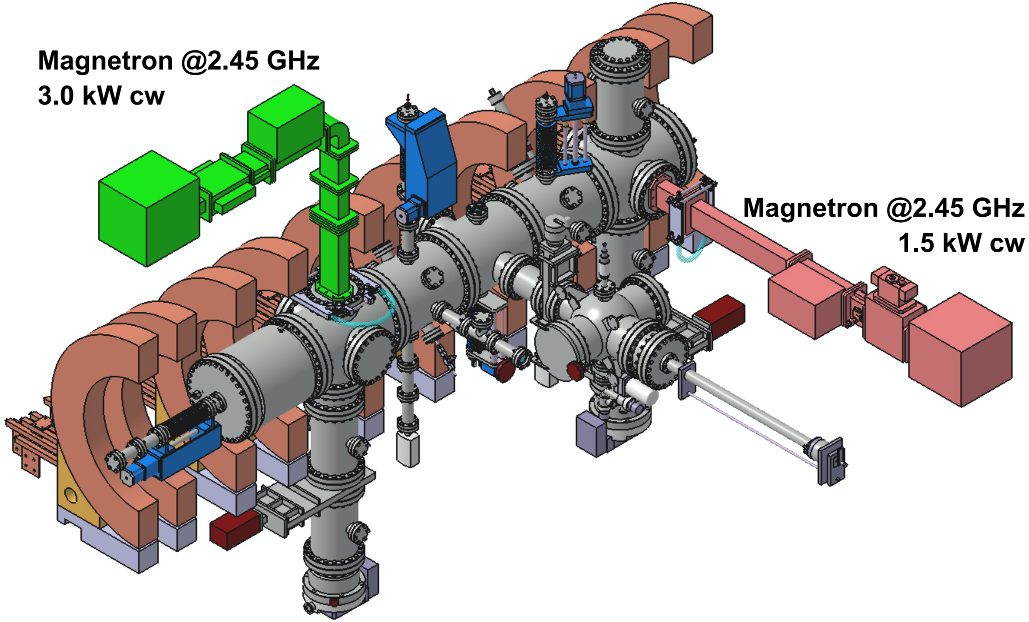
- Graphite substrates with irregular surface and silicon substrates with pyramids were covered with 500 nm compact W coatings
- W/Si samples were exposed to He plasma at 6 $He^+$ energies @ 4.0e24 $He^+$ $m^{-2}$
- W/Si quasi-static *Y* was evaluated from mass and thickness loss measurements
- No erosion for $E_{ion} \leq 200$ eV and for $E_{ion} \geq 250$ eV → $Y_{Flat} > Y_{Pyramids}$
- Mean value of surface inclination angle distribution good parameter to characterise surfaces
- $Y_{\Delta m} \ll Y_{Ion}$ → similar to what was observed in other LPD experiments
- $Y_{\Delta m} \ll Y_{ERO}$ at 350 eV but $Y_{Pyr.}/Y_{Flat}$ agrees → calibration of sputtering yields as input to ERO2.0 with $Y_{Flat,\Delta m}$ to quantitatively catch $Y_{Pyr.,\Delta m}$? (see SP D highlight talk of G. Alberti)
- W/Gr + $W_{bulk}$ exposure, characterisation and comparison with W/Si by year-end

Thank you!

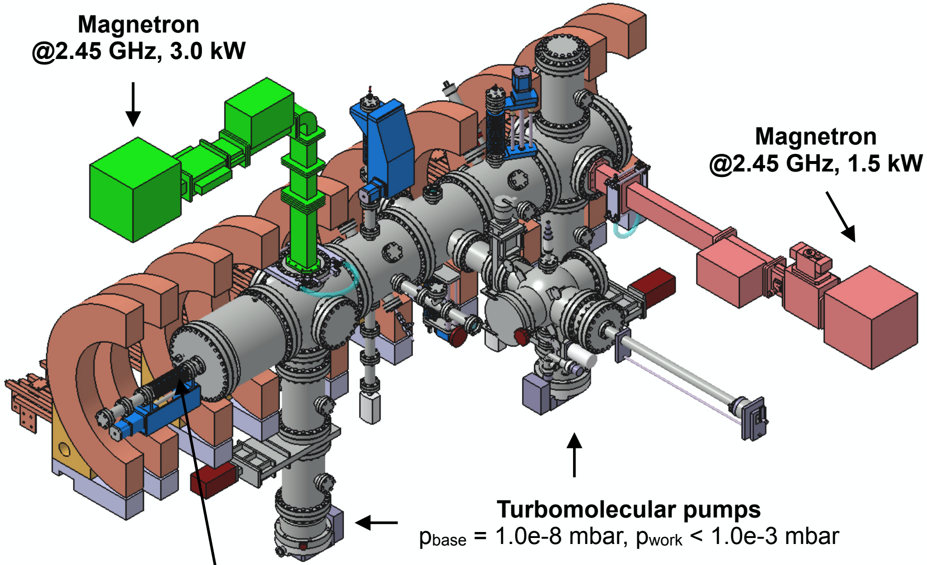
# GyM linear plasma device @ ISTP-CNR Milano

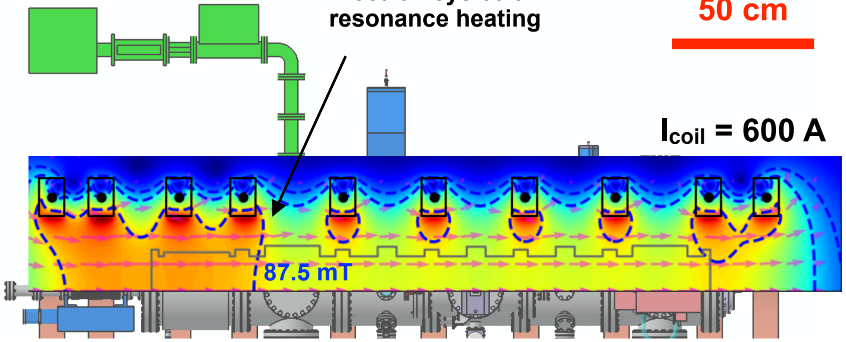
| | |
|---|---|
| Vacuum vessel | Stainless steel (SS): L = 2.11 m, Ø = 25 cm<br>(optional: SS liner with W coating) |
| Pumping system | 2 turbopumps: $p_{base}$ = 1E-8 mbar, $p_{work}$ < 1E-3 mbar |
| Working gas | $H_2$, $D_2$, $N_2$, He, Ar, He+$NH_3$ and mixtures |



# Linear plasma device GyM @ ISTP-CNR Milan




| | |
|---|---|
| $t_{pulse}$ [s] | Steady state |
| $Ø_{plasma}$ [cm] | 20 |
| $n_e$ [$m^{-3}$] | up to $10^{17}$ |
| $T_e$ [eV] | 3-15 |
| $T_i$ [eV] | <0.1 |
| Γ [ions $m^{-2}s^{-1}$] | up to $10^{21}$ |
| $Φ_{max}$ [ions $m^{-2}$] | $10^{25}$ (7 h) |

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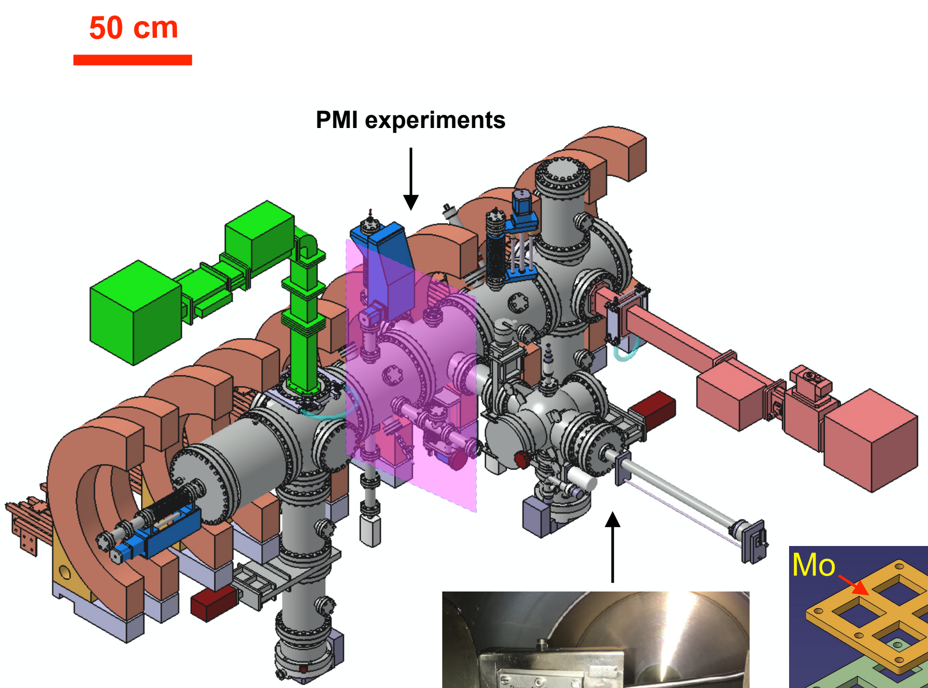


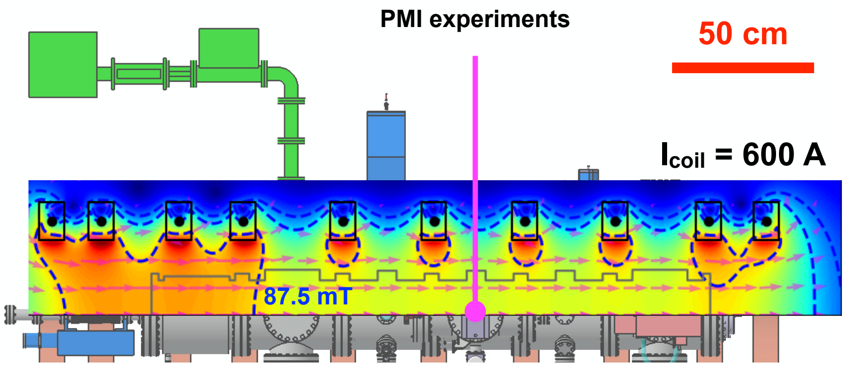


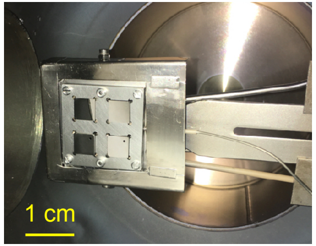


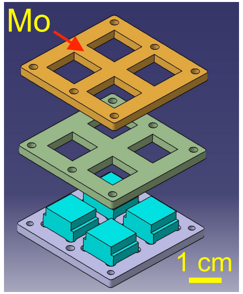


Sample exposure system + bolometry

| | |
|---|---|
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| Γ [ions $m^{-2}s^{-1}$] | up to $10^{21}$ |
| $Φ_{max}$ [ions $m^{-2}$] | $10^{25}$ (7 h) |
| Incident ion energy [eV] | 20-400 |

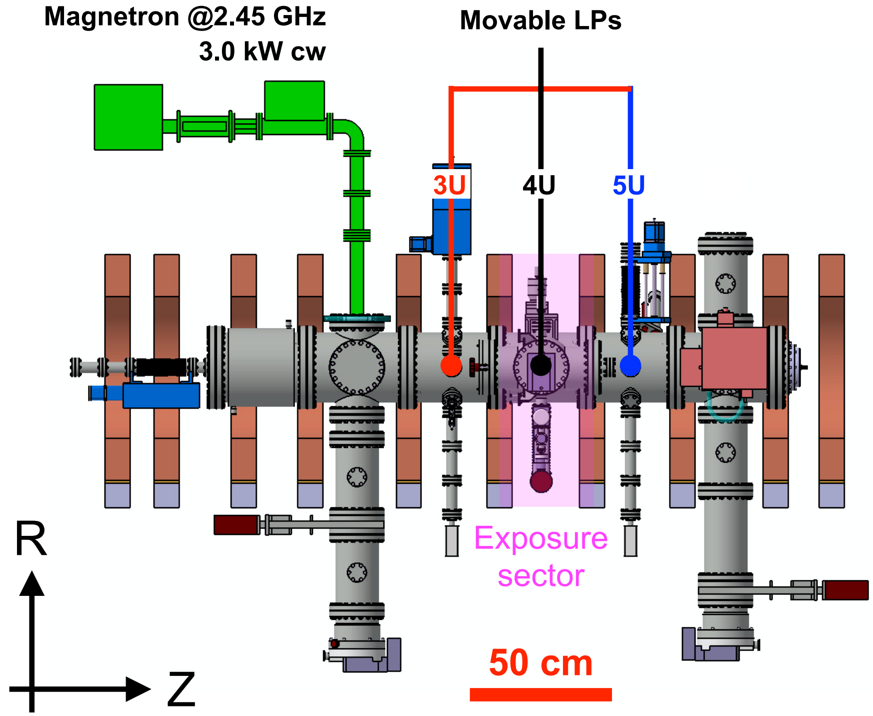
**Sample geometry**

PSI-2 standard

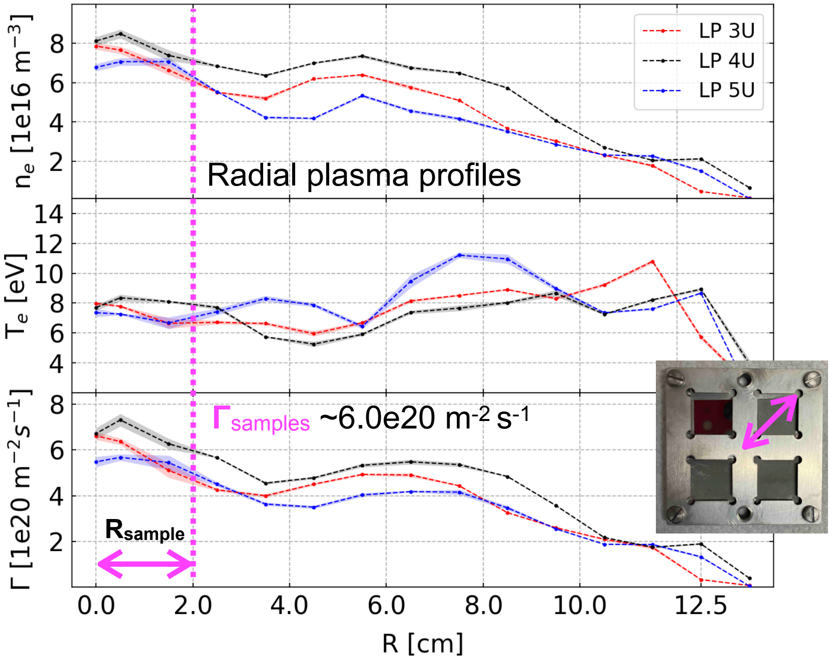
square slab
l = 12 mm - 0.2 mm
s ≤ 3 mm

# Characterisation of GyM He plasma by LPs and OES

- Optimisation of experimental conditions to obtain max and homogeneous $\Gamma_{He^+}$ on samples
- Provide full set of data for validation of SOLPS-ITER results of Polimi+ISTP for SP D.1 & 3




Opt. cond. → $I_{coil}$ = 600 A, $P_{source}$ = 1.2 kW, p = 0.10 Pa



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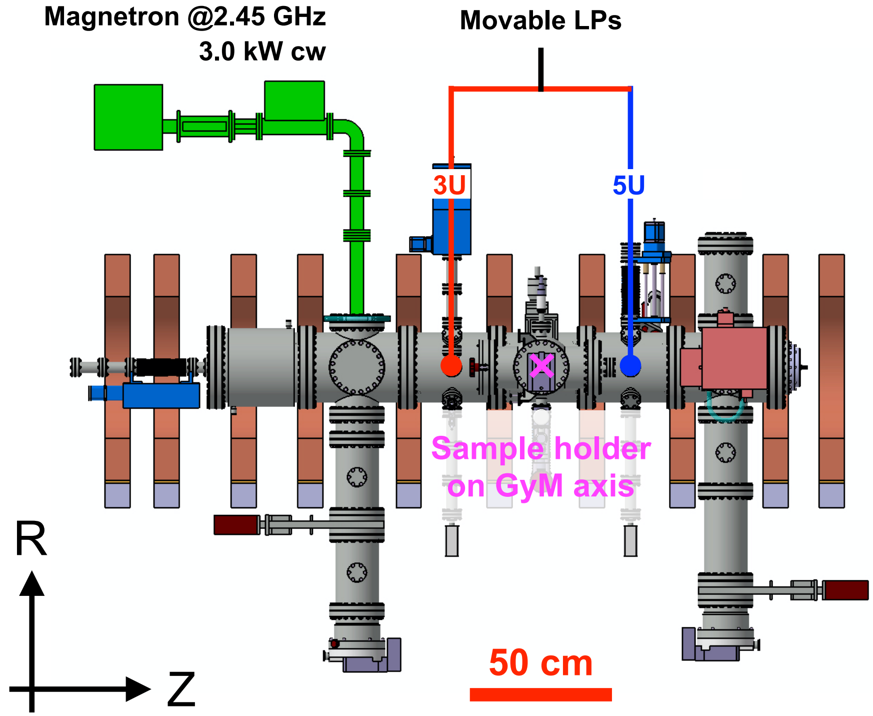


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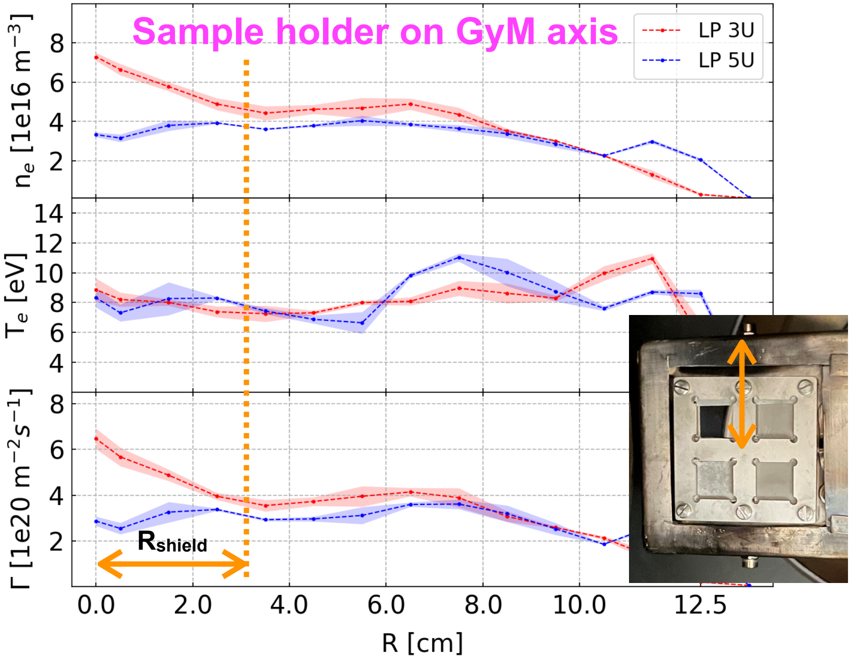
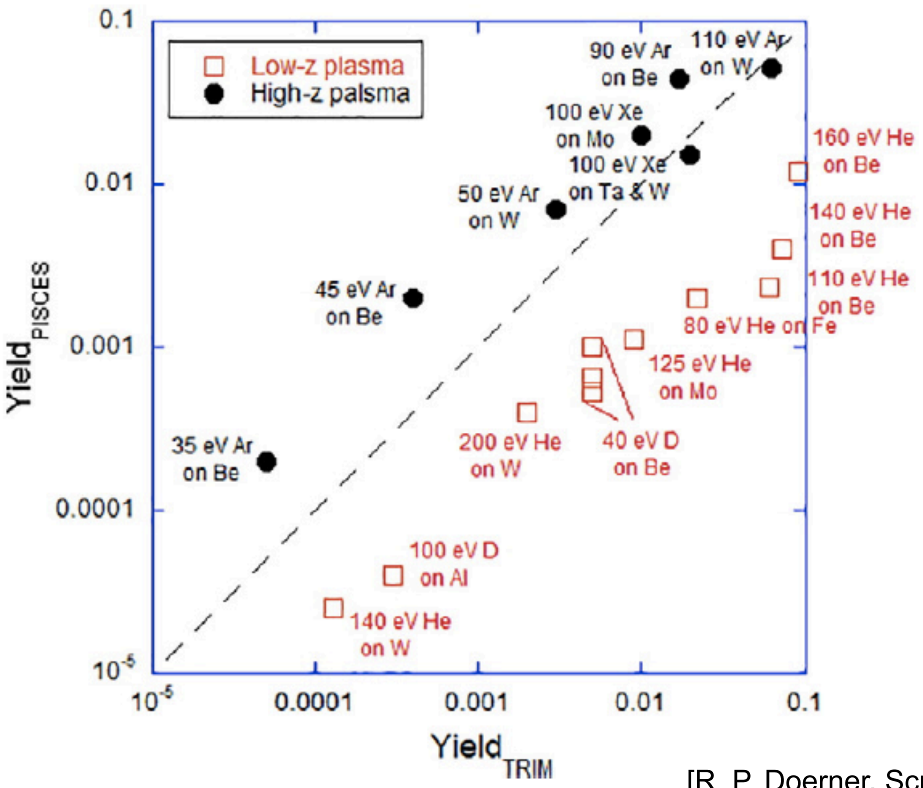


# …Side activity

*Study angular distribution of sputtered W particles from W/$Si_{py}$ with Catcher-QCM setup of ÖAW*

[B. M. Berger, et al., NIM-B 406(2017)533-7]

- 2 **Si** substrates with pyramids and $R_a$ = 500 - 600 nm (ISTP) ✓
- 2 **Si** substrates with pyramids and $R_a$ = 900 - 1000 nm (ISTP) ✓
- 2 **Si** flat substrates ✓
- Deposition of compact **W coatings** (Polimi) ✓
- AFM analysis of W/$Si_{py}$ (ISTP) ✓
- Shipping to Wien ✓




[R. P. Doerner, Scr. Mater. 143 (2018) 137-141]