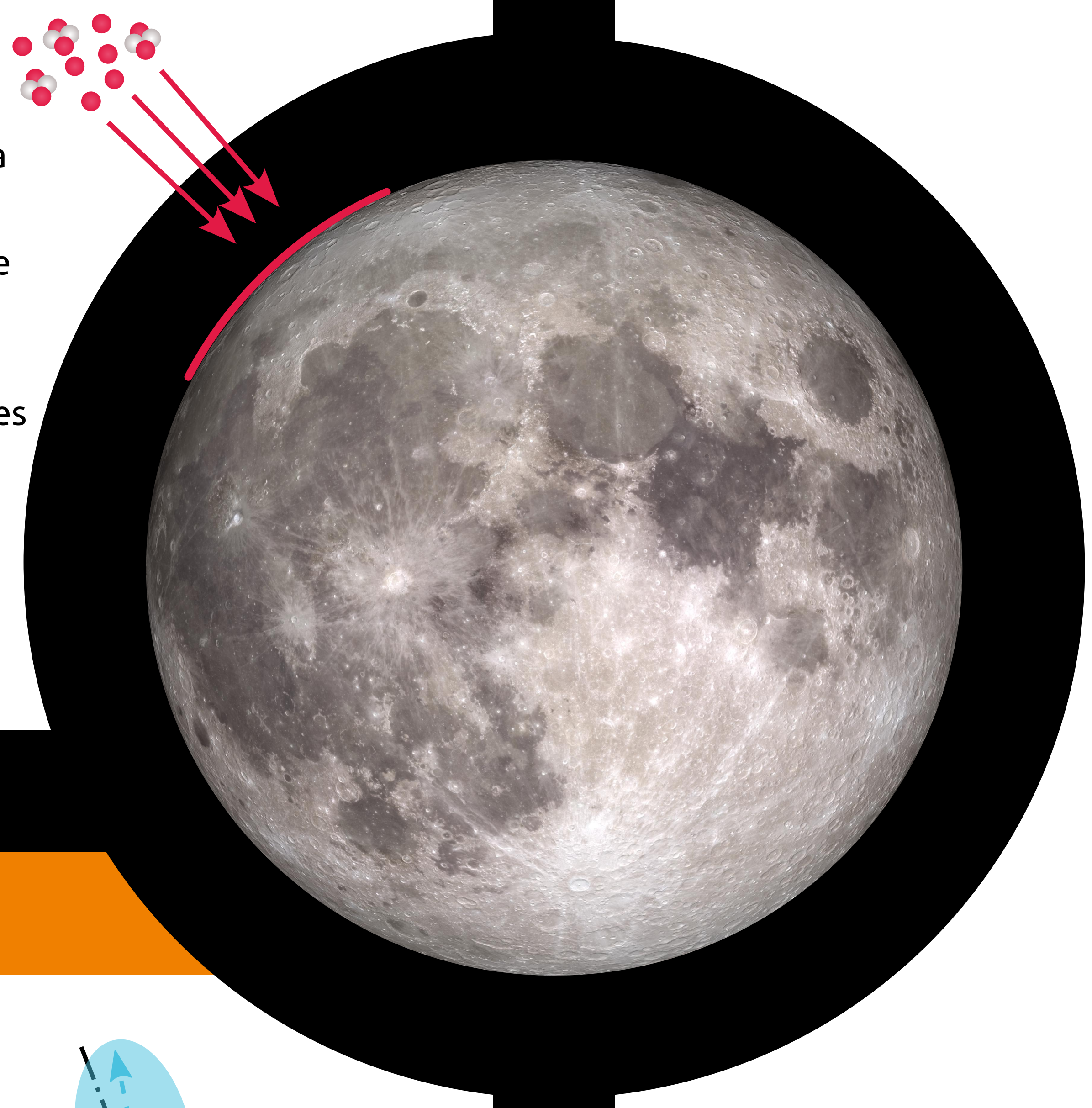
# A comprehensive study on the sputtering of the Lunar surface

**J. Brötzner[a], H. Biber[a], N. Jäggi[b,c], A. Nenning[d], L. Fuchs[a], P.S. Szabo[e], A. Galli[b], P. Wurz[b] and F. Aumayr[a]**

[a]Institute of Applied Physics, TU Wien, Vienna, Austria
[b]Physics Institute, University of Bern, Bern, Switzerland
[c]Department of Material Science and Engineering, University of Virginia, Charlottesville, USA
[d]Institute of Chemical Technologies and Analytics, TU Wien, Vienna, Austria
[e]Space Sciences Laboratory, University of California, Berkeley, USA

## Introduction

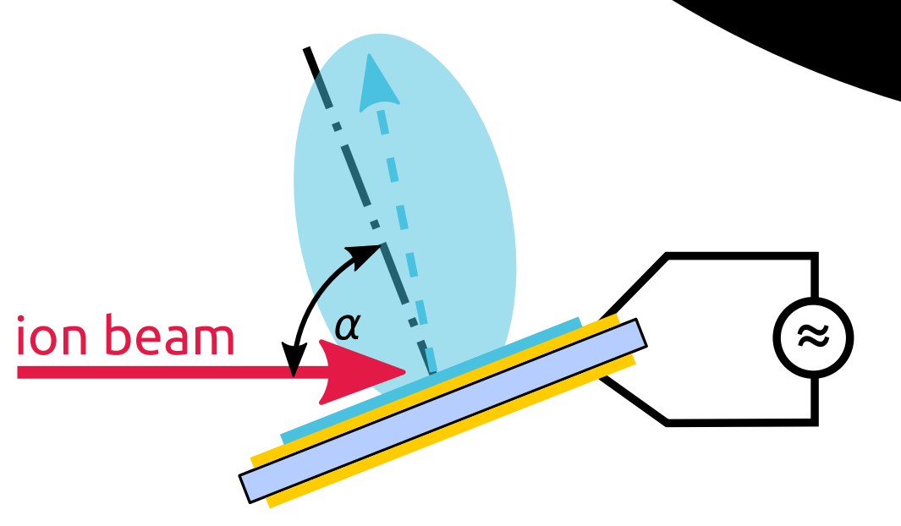
- The solar wind (~96% $H^+$, ~4% $He^{2+}$) can impinge directly on the dayside of the lunar surface, releasing material via **ion sputtering.**
- Among other processes, this is a source mechanism in the formation of the lunar exosphere, noteworthy for the supra-thermal ejecta energies.
- Often, exosphere models rely on popular sputtering codes for input data on the sputtering contribution without further validation.
- We aim to constrain three physical quantities describing the sputtering process: angular distribution, sputtering yield and energy distribution.



## Methods

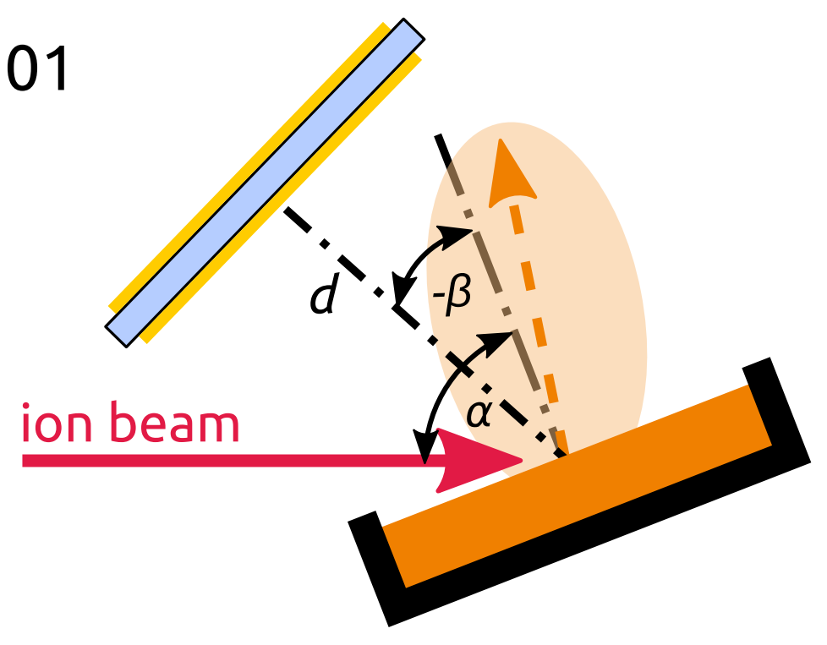
**Quartz Crystal Microbalance (QCM) [1]**

- $\frac{\Delta m}{m} = -\frac{\Delta f}{f}$ [2]
- Resolves mass changes of thin films in real time
→ direct sputter yield determination
- Used sample: thin film grown from Apollo 16 #68501



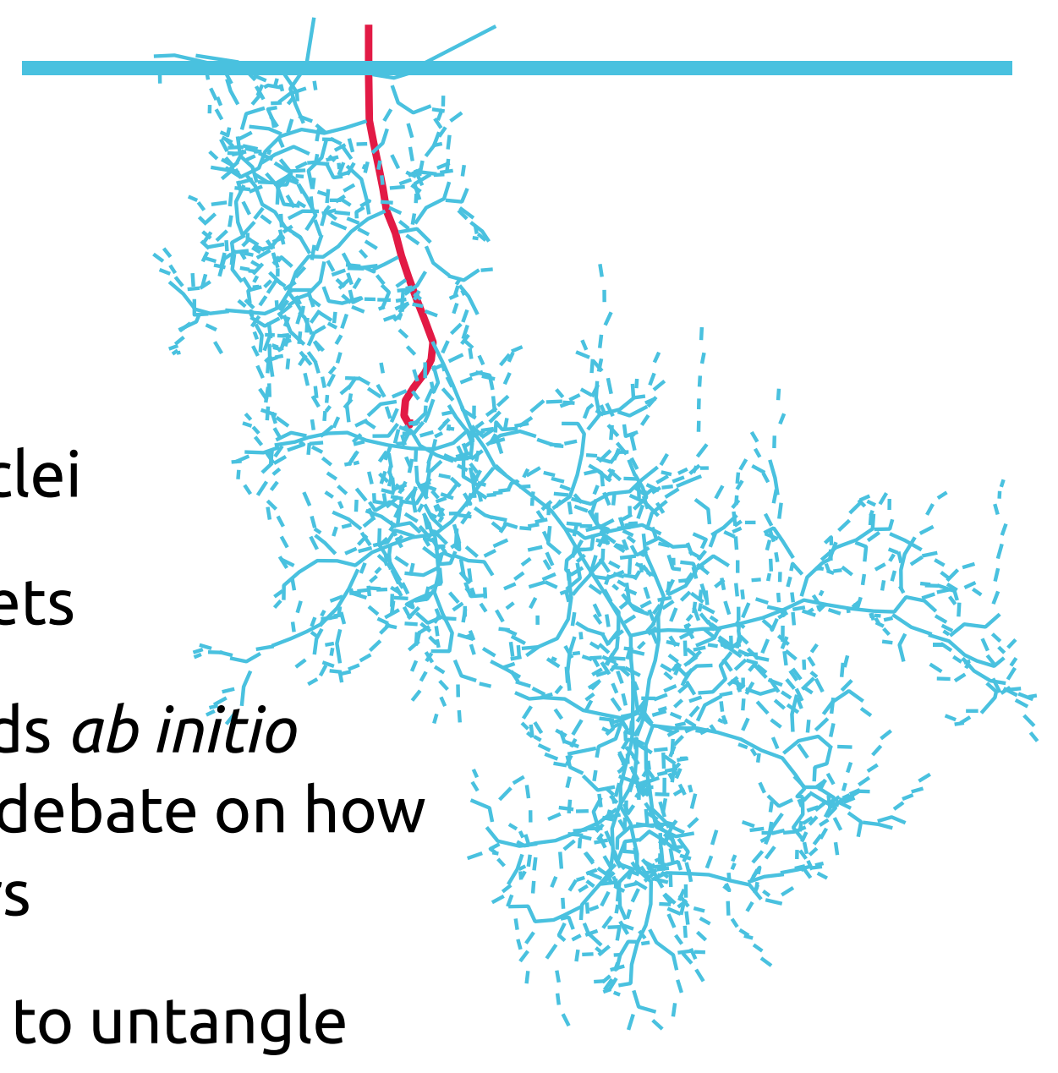
**Catcher QCM [3]**

- Second QCM facing the samples, collecting ejecta
- Probes angular distribution of released particles
- With calibration through the thin film
→ obtain sputter yields of bulk samples indirectly
- Used sample: pressed pellet [4] from Apollo 16 #68501

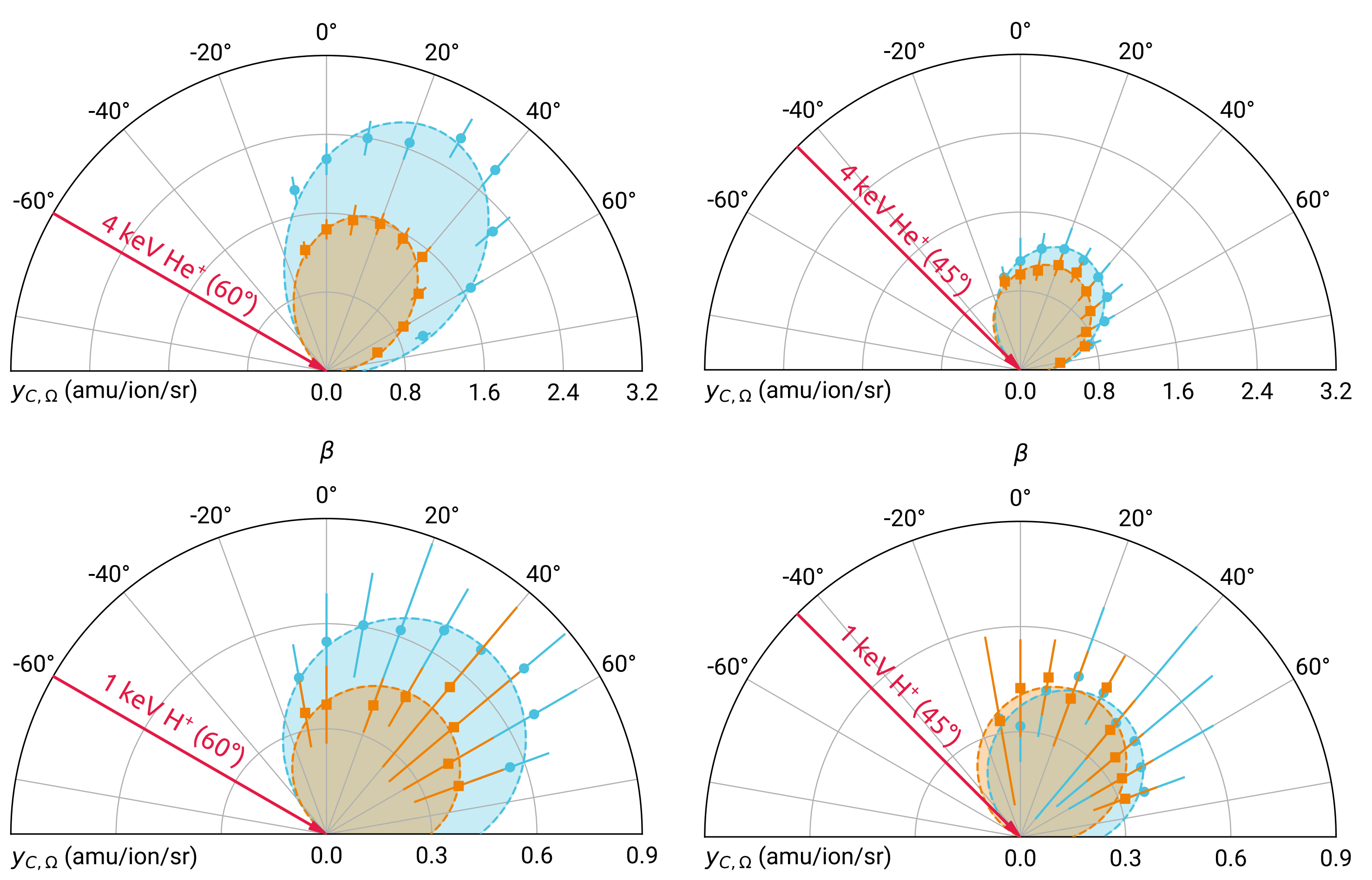


**Simulations – SDTrimSP [5, 6]**

- Track simulated ions and their generated recoils through a solid
- Binary Collision Approximation (BCA): assumes a series of independent collisions between two nuclei
- Most basic version assumes flat, amorphous targets
- Cannot usually correctly calculate sputtering yields *ab initio*
→ experimental benchmarks important, ongoing debate on how to sensibly choose the variety of input parameters
- SDTrimSP-3D: three-dimensional variant allowing to untangle surface topography effects from intrinsic material properties



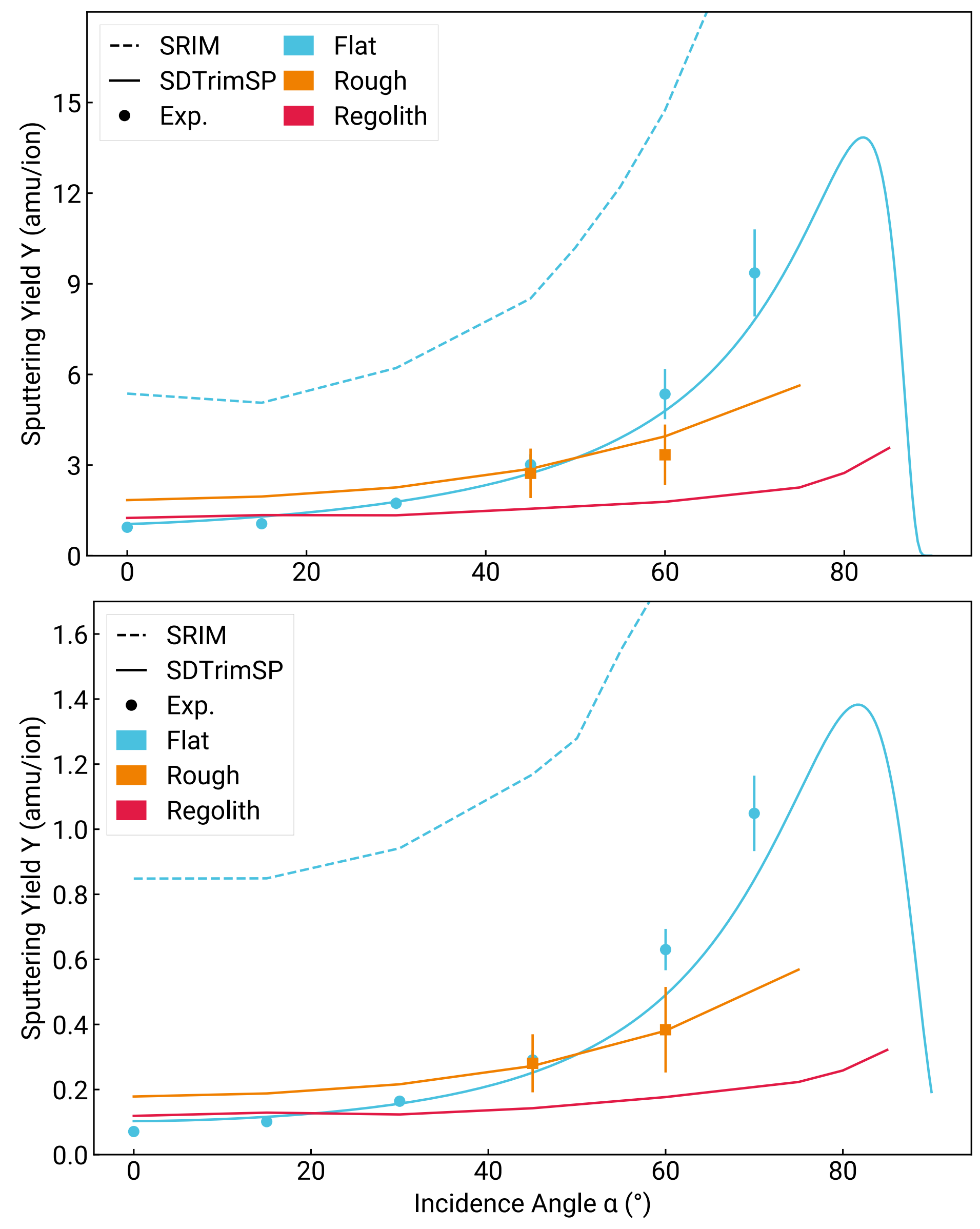
## Ejecta angular distributions



- Mass stuck to catcher QCM as a function of polar angle β (cf. sketch above)
- Reduction in sputtered mass for grazing impact and rough samples

QCM used to compare ejecta angular distributions across sample types

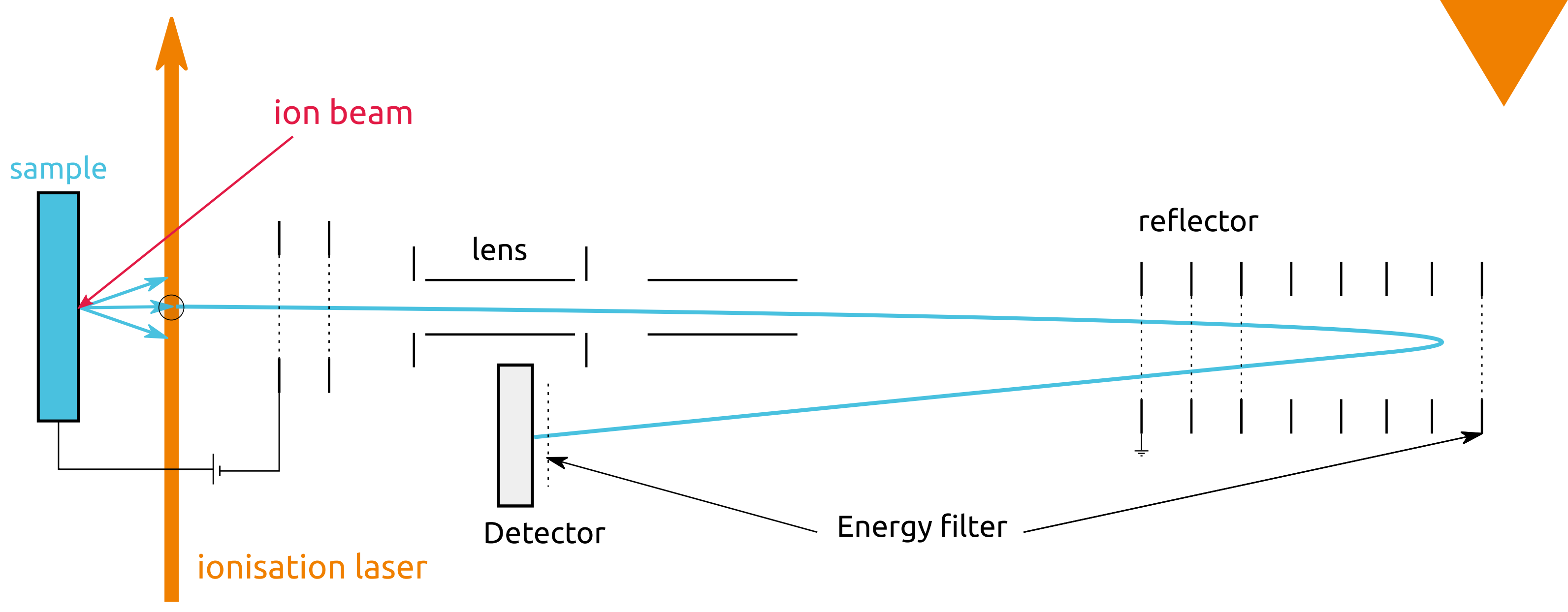
## Sputtering yields



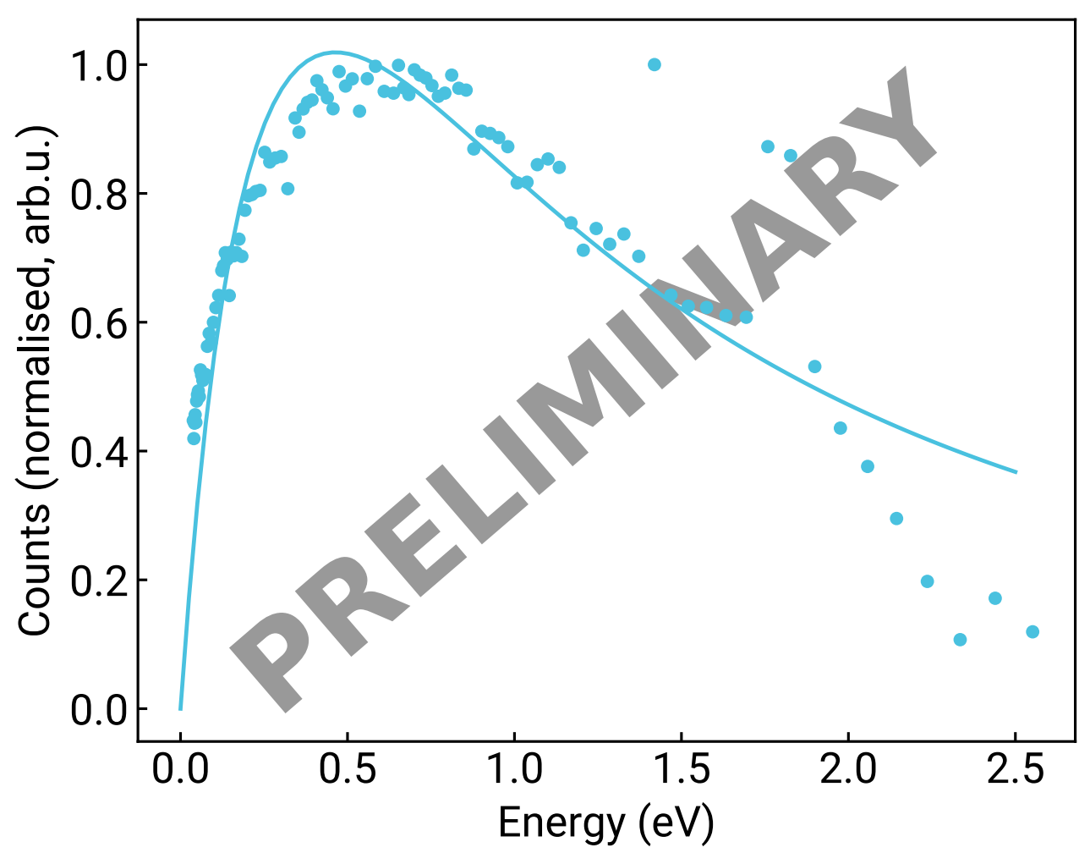
- Investigations carried out for both He and H (upper and lower figure, respectively) at solar wind energies (1 keV/nucleon)
- Influence of surface morphology: The increase in roughness when going from the thin film sample to the pellet decreases the sputtering yield and suppresses the dependence on the incidence angle
- This reduction is observed both in experiments and simulations [7]
- Red line: simulations for porous structures modelled after [8], representative for the conditions in the Lunar regolith
- SRIM (dashed): previous assumptions

Sputtering yields have been severely overestimated!

## Ejecta energy distributions



- Proposed method for measurements: Time of Flight – Secondary Neutrals Mass Spectrometry **(ToF–SNMS) [9]**
- Most sputtered particles neutral
→ ionise using a focused laser
- Timing between ion pulse, ionisation and extraction and knowledge of distance between sample and ionisation volume gives kinetic energy of ejecta
- Time of flight difference between particles of same energy gives mass resolution
- Proof-of-principle campaign at the University of Duisburg-Essen showed feasibility, however some improvements are still necessary:
  - Better knowledge of the ionisation volume position
  - Laser capable of ionising also Si, O



- Figure above: energy distribution of Mg sputtered by Ar ions from a $MgSiO_3$ thin film
- "Thompsonic " behaviour (fit line) visible, even though high energetic particles not detected as efficiently

ToF–SNMS seems to be a well-suited experimental approach!

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