Measurement of Ion-Impact Desorption (IID) Cross Sections of Deuterium from Tungsten

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Abstract

Desorption of hydrogen isotopes during ion bombardment plays a key role in the fuel recycling process within the edge-plasma of a fusion device. We report measurements of the ion-impact desorption (IID) cross section of deuterium from polycrystalline tungsten due to low-energy Ne^+ irradiation at a series of incident angles.

Motivation

- Interactions of neon plasmas and material surfaces occur due to presence of neon in edge plasma used for gas-puff imaging (GPI) experiments, or to manipulate edge-plasma parameters, and use of neon to increase radiative cooling of plasma in divertor regions.
- Removal of deuterium (or tritium) due to energetic Ne^+ bombardment generates a energetic, deuterium flux into the plasma.

Outline

1. Ion-Impact Desorption
2. Measurement Technique
3. Experimental Details
4. Data Analysis
5. Results and Conclusions

Ion-Impact Desorption (IID)

- Removal of surface atoms due to collisions with impinging ions
- A subset of ion-induced desorption strictly speaking
- Kinematics modeled using binary collision approximation (BCA)
- Cross section measured instead of sputtering yield of adsorbate as target population changes with time (ion fluence)

Model: Basic Assumption

- Assuming a *linear* relationship between the removal rate and the coverage, or

$$\frac{d\theta(t)}{dt} \qquad \theta(t)$$

$$\frac{d\theta(t)}{dt} = \Phi\sigma_d\theta(t)$$

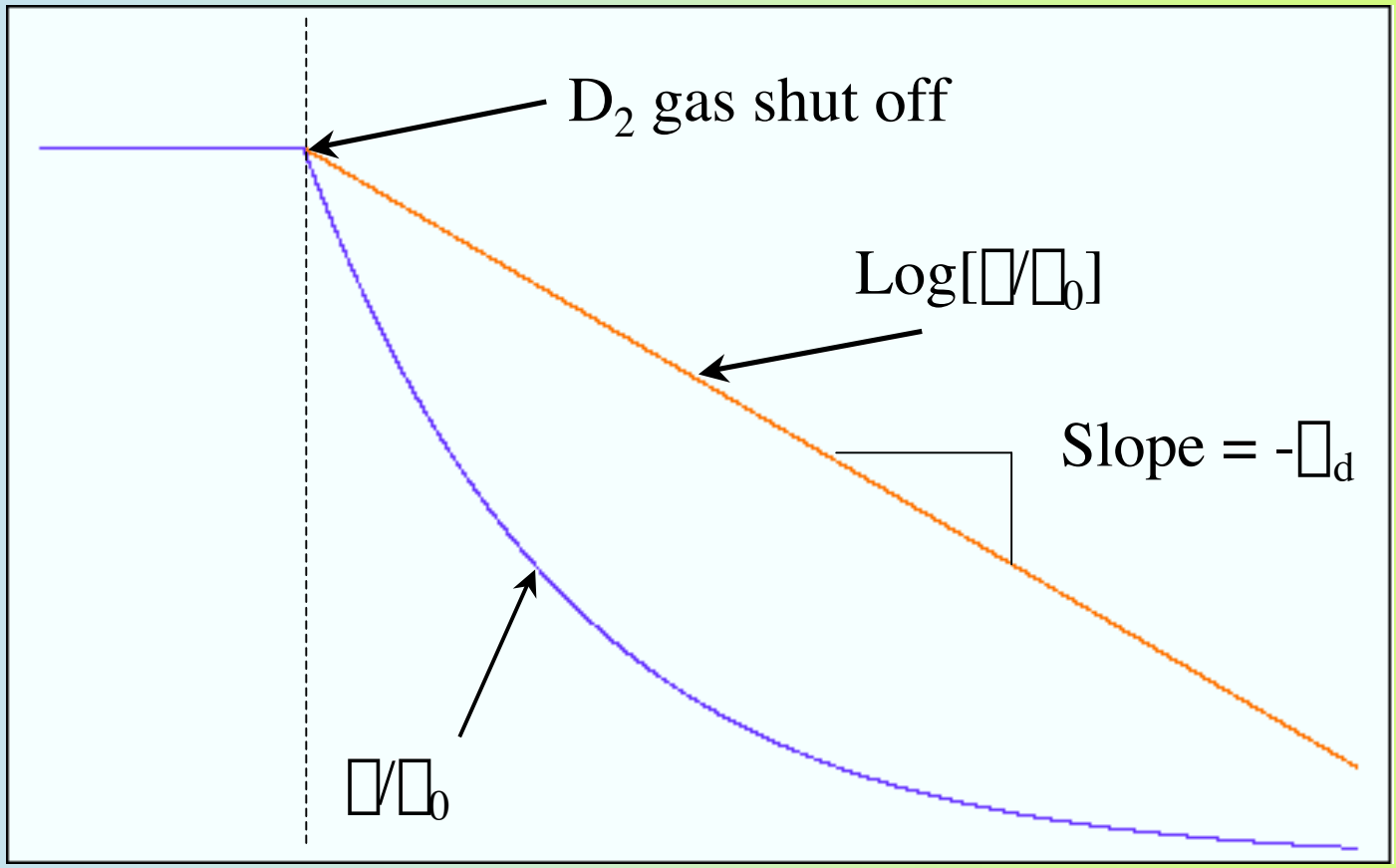
  - $\theta(t)$ represents the fractional surface concentration of a particular species ($0 < \theta < 1$)
  - Φ is the ion beam flux ($cm^{-2}s^{-1}$)
  - σ_d is the desorption cross section (cm^2)

Model: Relative Coverage

$$\ln\left[\frac{\square(t)}{\square_0}\right] = \square\square\square_d\, t = \square\square\square_d$$

- $\square$ is the ion fluence (cm^{-2})
- Shows only ***relative*** coverage information needed
- Eliminates many experimental & data analysis sources of error
- Limitation: This model is only valid for non-interacting adsorbates

Ideal Plot: Coverage vs. Fluence



Ion Fluence (Arbitrary Units)

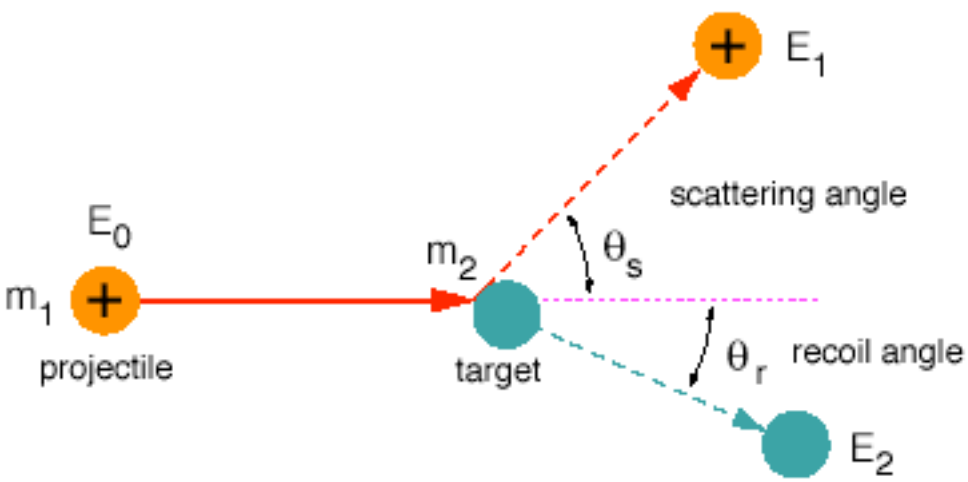
Measurement Approach

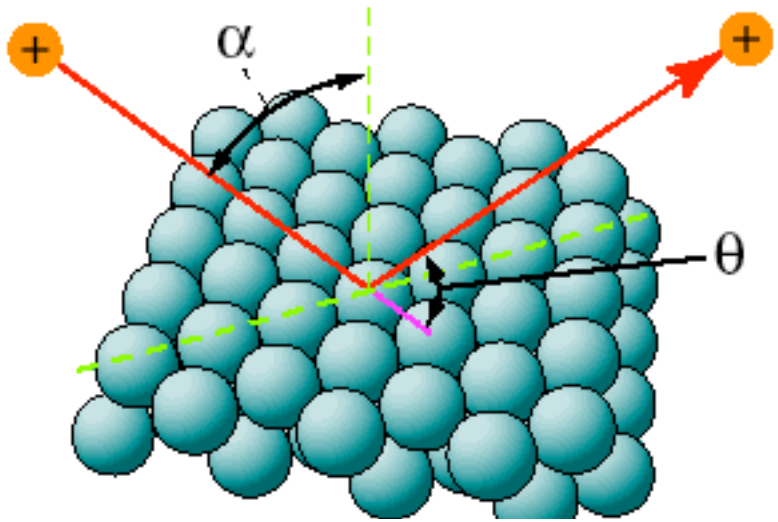
- **Objective**: Determine reduction in surface coverage as a function of ion fluence to obtain desorption cross sections
- **Method of Choice**: Low-Energy Ion Scattering / Direct Recoil Spectroscopy (LEIS/DRS)
- **Reasoning**: LEIS/DRS (in addition to SIMS) can do two things in particular that other practical methods cannot

  (1) Surface specificity: Absolute quantities on the uppermost atomic layers are resolvable

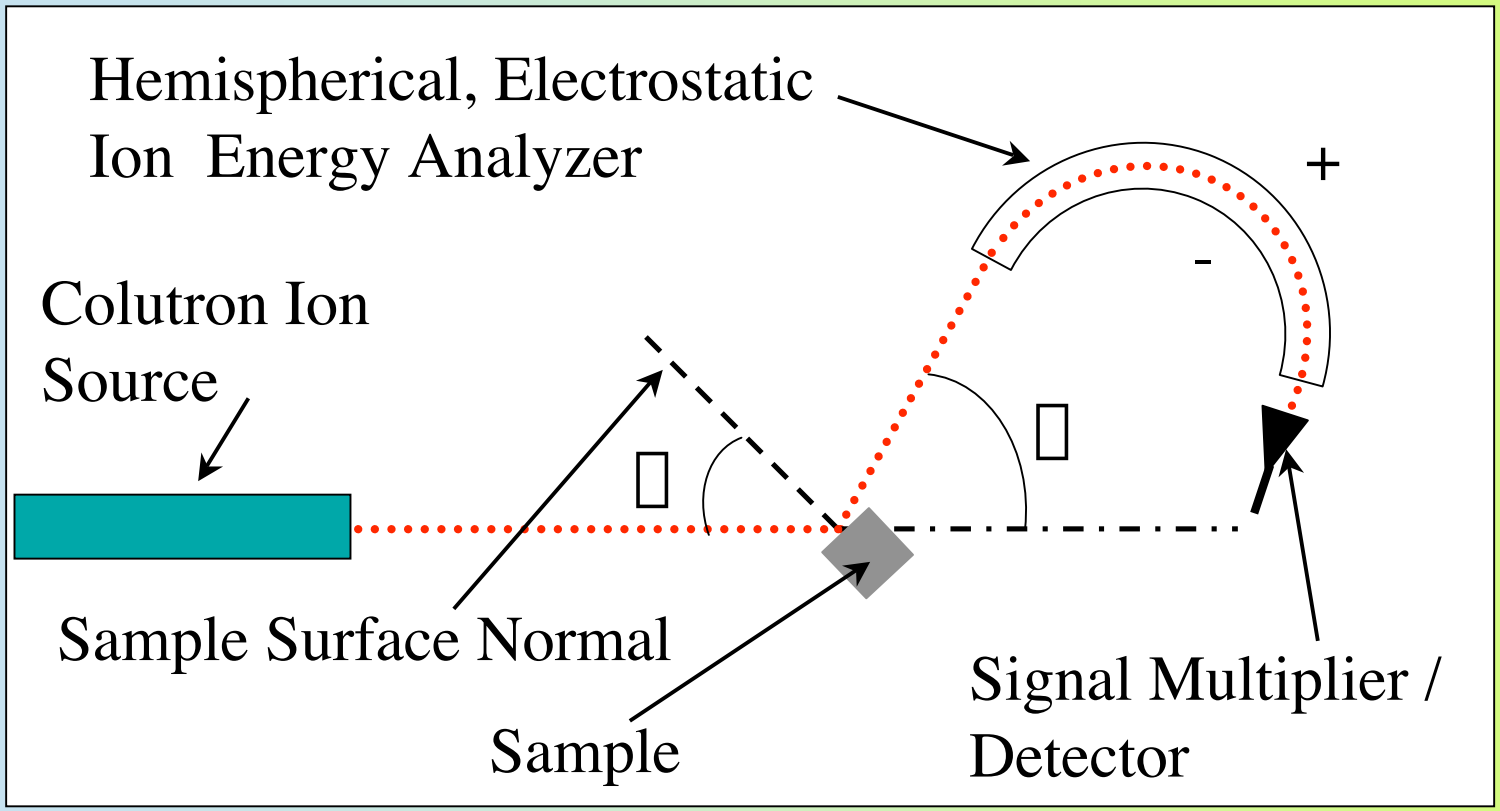
  (2) Detect hydrogen isotopes: Hydrogen isotopes are measurable both indirectly (LEIS) and directly (DRS)

Measurement Technique: LEIS/DRS





ARIES: Angle-Resolved Ion Energy Spectrometer



Typical Ions: Ne^+, He^+, D^+, Ar^+ etc. ~ 300-3000 eV

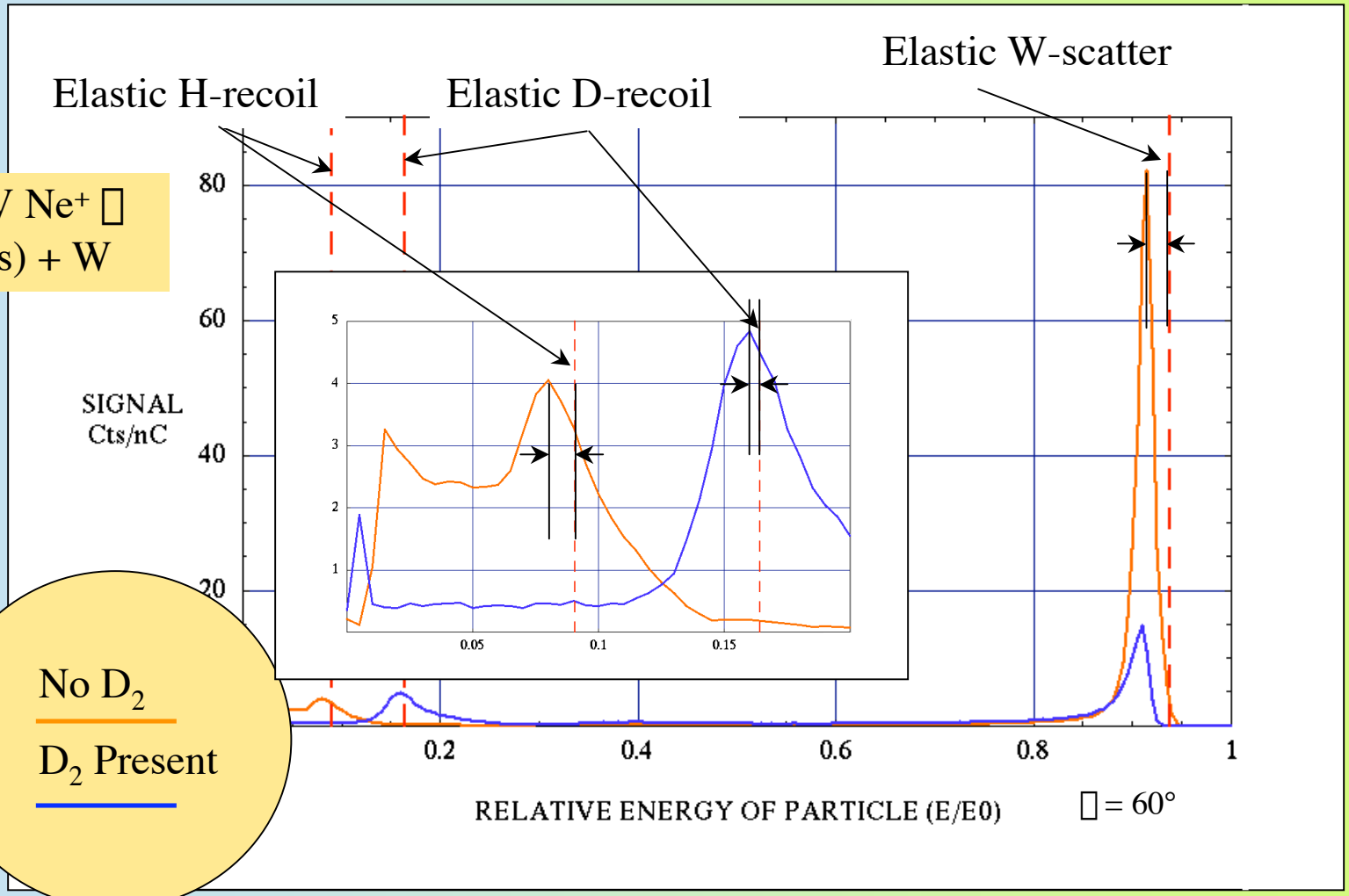
Kinematic Relations

- Conservation of energy and linear momentum in the lab frame show
  - $$2\,Cos\theta_{SCAT} = (1+A)\sqrt{E_{SCAT}} + \frac{(1-A)}{\sqrt{E_{SCAT}}}$$

and…

  - $$2\,Cos\theta_{REC} = (1+A)\sqrt{\frac{E_{REC}}{A}}$$

Ion Energy Spectrum of W w/ and w/o D_2 in chamber



Calculation: ***Absolute*** Coverage

Signal is given by

$$S_i = P_0 \, p_i^{+} \, N_i \sigma_i$$

$$\theta_i = \frac{S_i / (p_i \sigma_i)}{\sum_j \left[S_j / (p_j \sigma_j) \right]}$$

- S_i is the signal strength of species i
- P_0 represents effects due to experimental conditions (e.g. beam current, detector efficiency…)
- p_i^+ is the ion survival probability (small number for noble gas ions) due to interaction (scatter or recoil) with species i
- N_i is the areal number density of species i
- σ_i represents the interaction cross section (scatter or recoil) of the incident ion with the surface species i

Calculation of ***Relative*** Coverage

- Since the only varying term in the equation while following the temporal behavior of ***a single species*** is the coverage…

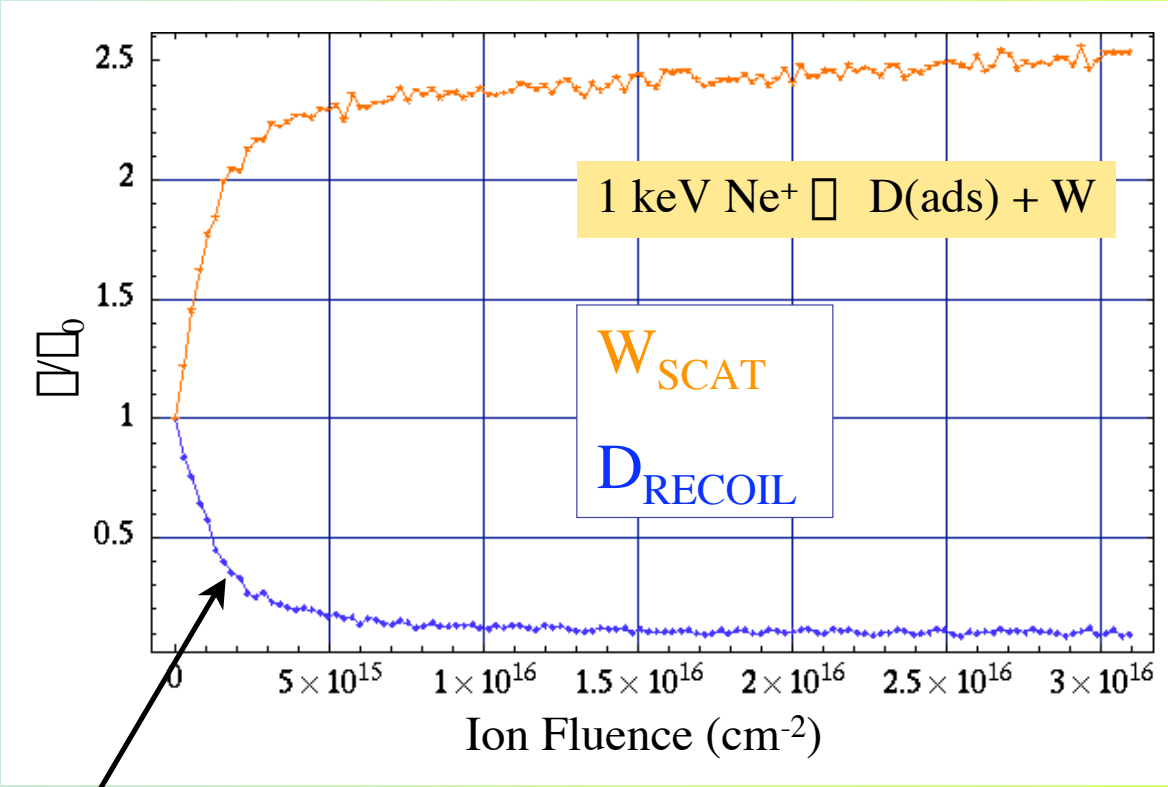
$$\theta_i \quad S_i$$

Thus…

$$\boxed{\frac{\theta_i(t)}{\theta_i(t=0)} = \frac{S_i(t)}{S_i(t=0)}}$$

Raw Data Example: Signal vs. Fluence Plot

- Data recorded from the time that the D_2 feed to the chamber was cut off
- Background (zero coverage) signal present



Signal of Interest

1 keV Ne^+ → W + D (ads)

$\theta = 65°$ $\phi = 60°$

Log[Relative Coverage] vs. Fluence Plot

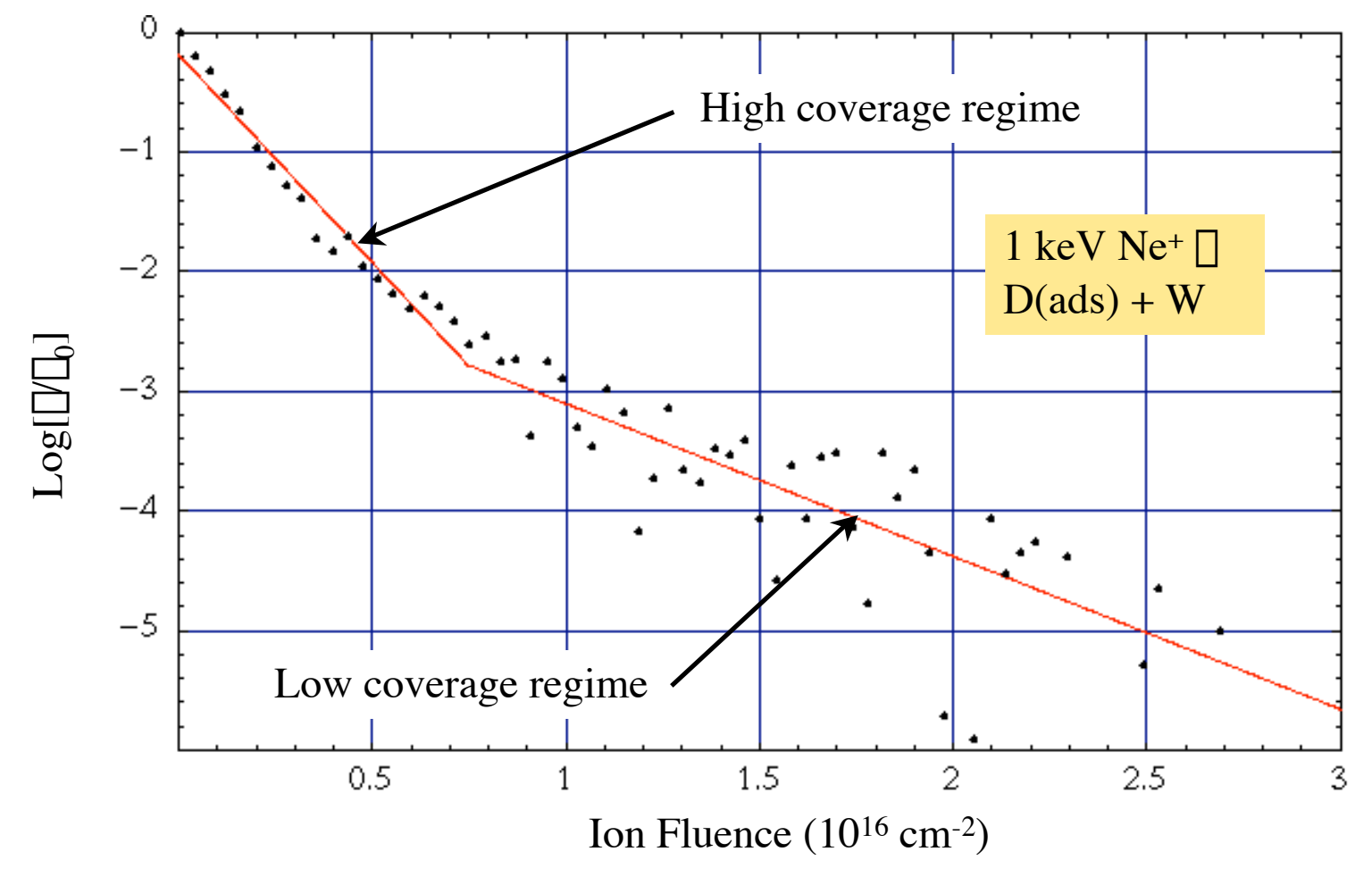


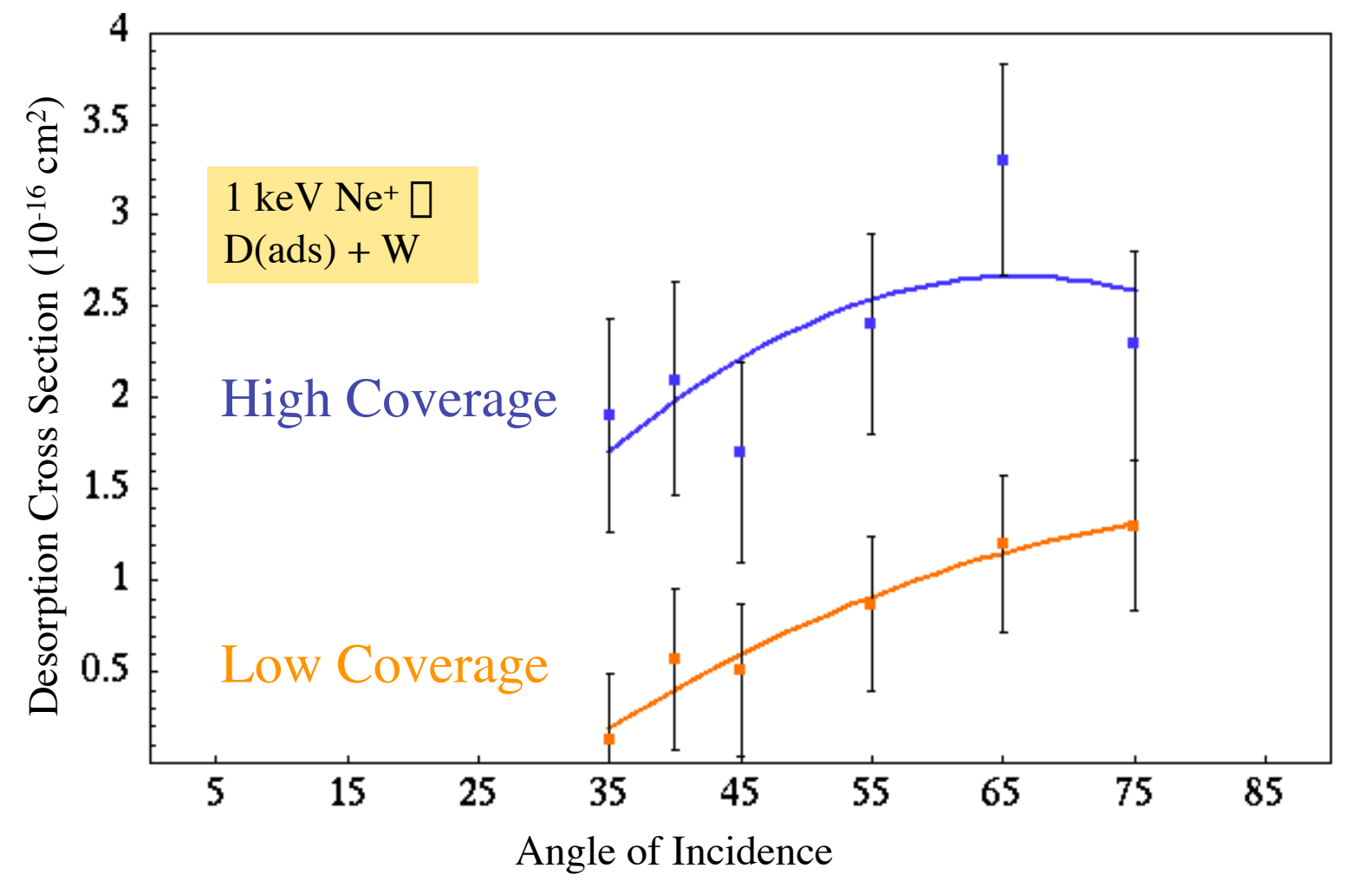
Table of Results

Angle of incidence	σ_{DES} (10^{-16} cm^2) high-coverage	σ_{DES} (10^{-16} cm^2) low-coverage
35	1.9	0.13
40	2.1	0.57
45	1.7	0.51
55	2.4	0.87
65	3.3	1.2
75	2.3	1.3

1 keV Ne^+ → D(ads) + W

$\theta = 60^o$

Angular Dependence of σ_{des}



Summary

- We reported ion-impact desorption cross section information for D on polycrystalline W due to low-energy Ne^+ beam irradiation at oblique incidence.
- Two distinct regimes emerged: low coverage and high coverage. The data for the high coverage situation are more reliable due to better statistics (higher target number density) and more relevant for fusion applications. The presence of the two regimes could be indicative of two principal types of binding sites on the polycrystalline W surface for deuterium.

Acknowledgments

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Questions…?