Angular Distribution Measurements of Sputtered Particles at UCSD

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for
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- QMS measurements in unmagnetized plasma
  - Moly
  - Carbon clusters
- Optical measurements in PISCES-B

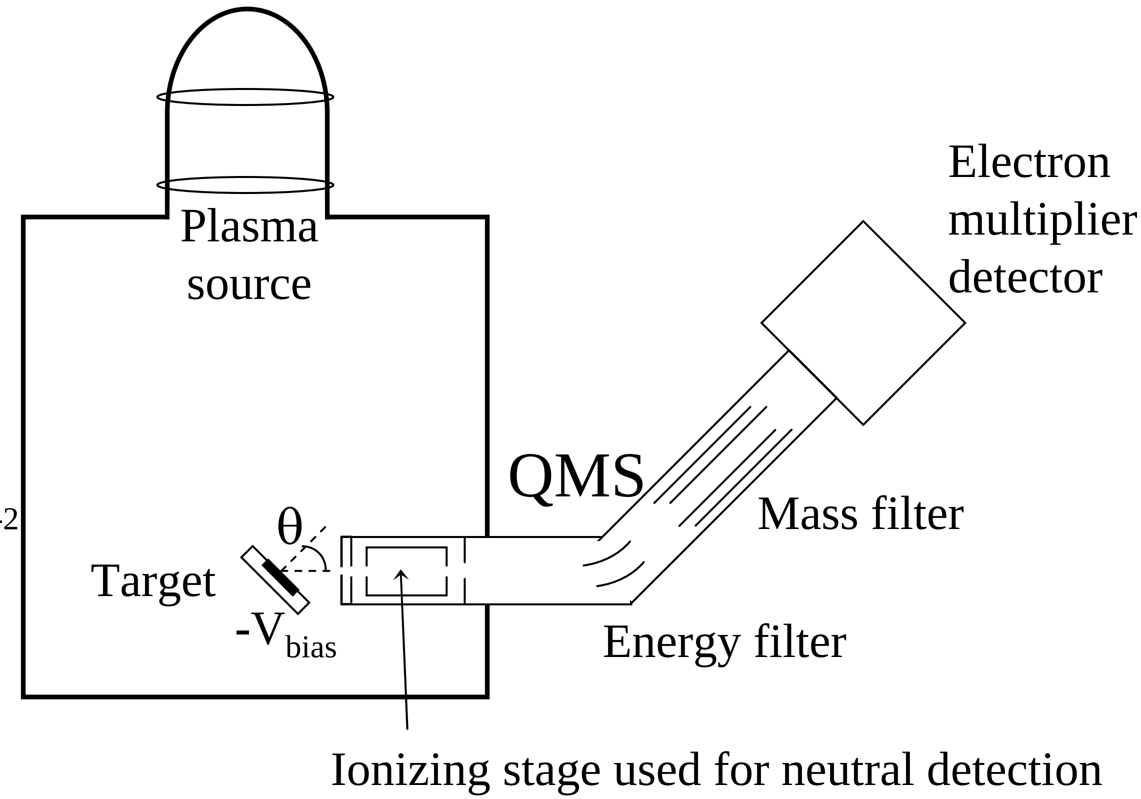
Angular distribution of sputtered Mo and C

Jonathan Yu and Eider Oyarzabal
April 26, 2005

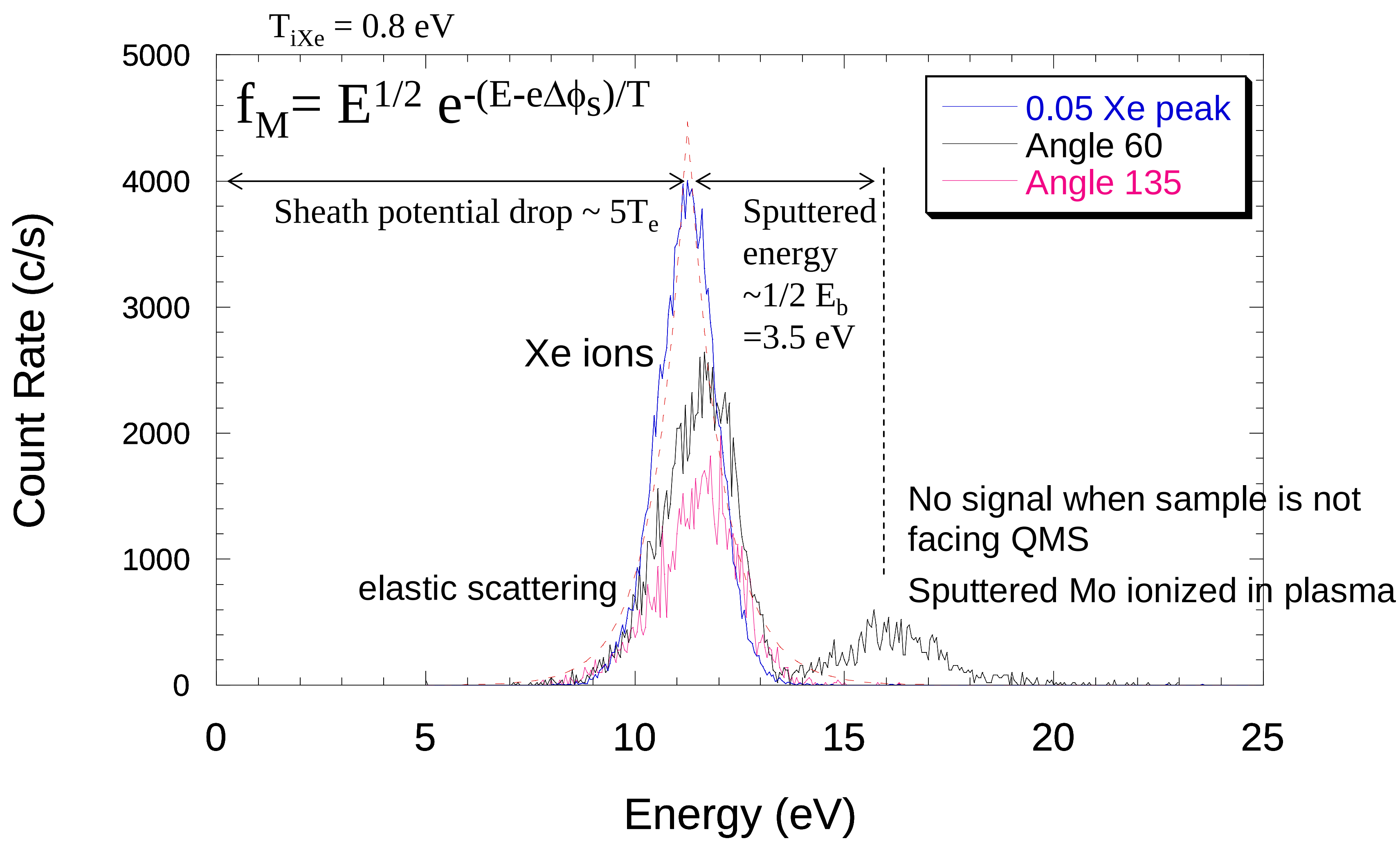
- Sputtering of grids is a critical issue for ion thruster lifetimes.
- Modeling requires measurement of angular distribution of sputtered atoms.
- Previous sputtering measurements: profilometry, weight loss, visible spectroscopy.
- Here, we use an energy-selecting mass spectrometer to detect sputtered ions.

Plasma Chamber and Quadrupole Mass Spectrometer (QMS)

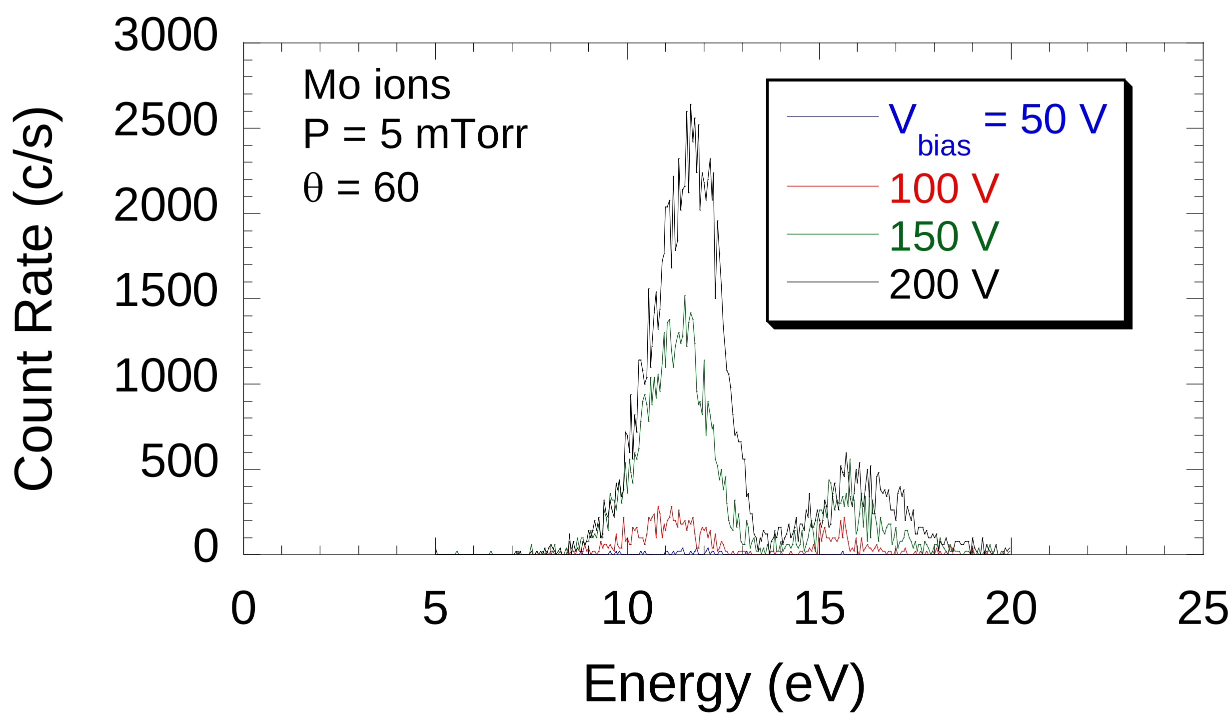
$n = 10^{11} - 10^{12}$ cm^{-3}
$T_e = 1 - 3$ eV
$P = 1 - 5$ mTorr
$\Gamma \sim 10^{18}$ ions s^{-1} cm^{-2}



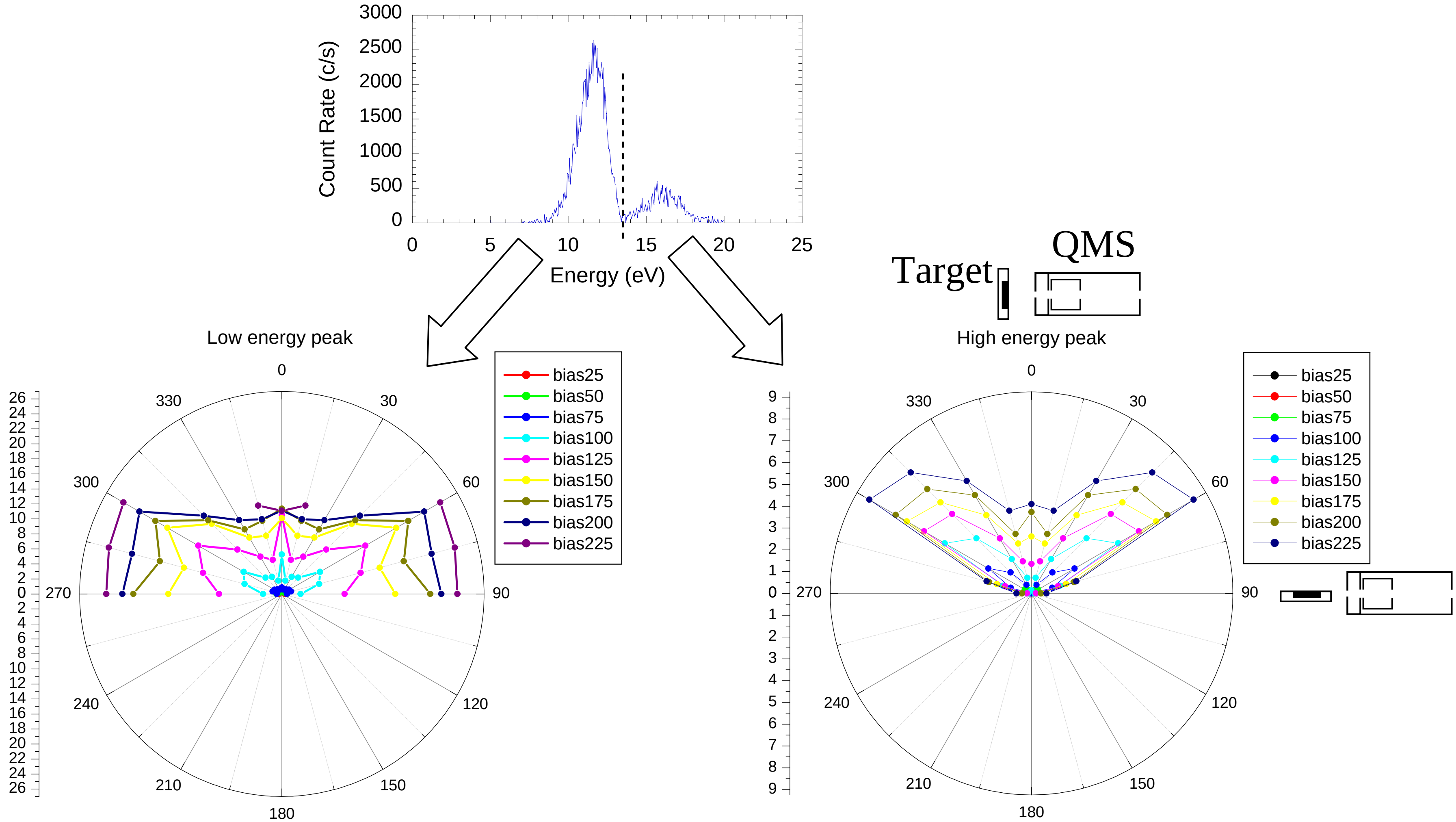
Mo sputtering with Xe plasma; Ion detection



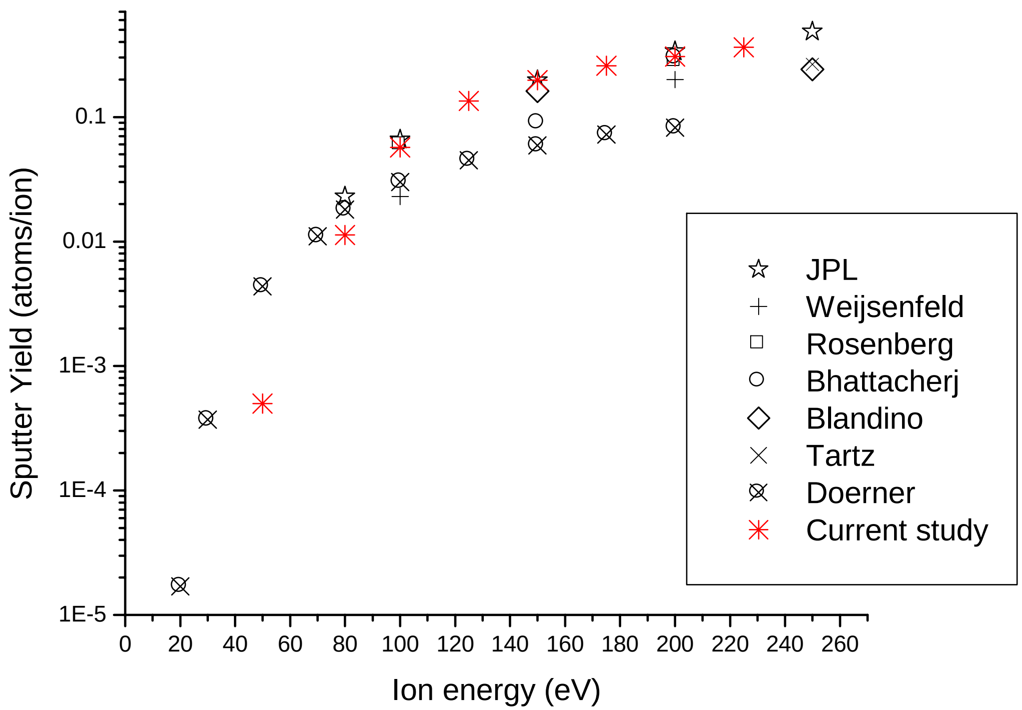
Mo ion sputtered signal increases with plasma ion bombardment energy



Angular distributions of low and high energy Mo ions

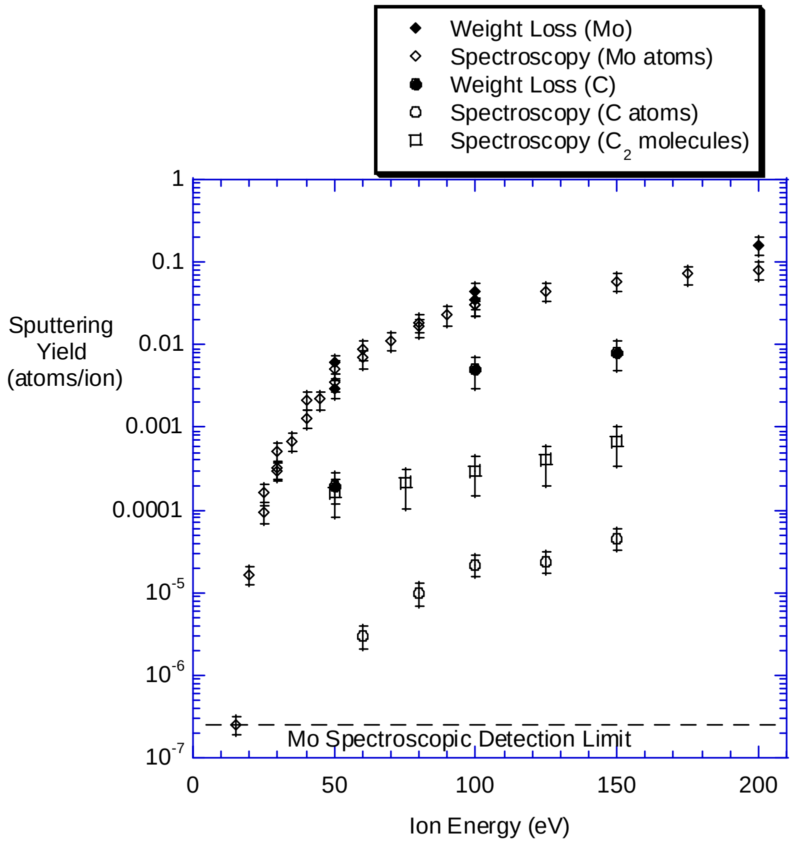


Xe on Mo comparison with other work



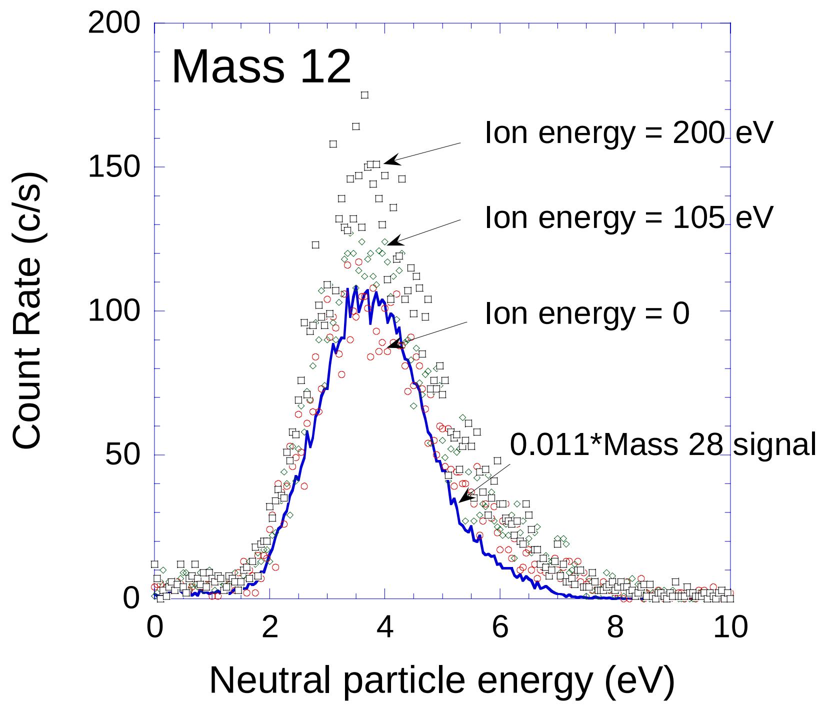
Carbon weight loss is not explained by atom sputtering and chemical processes

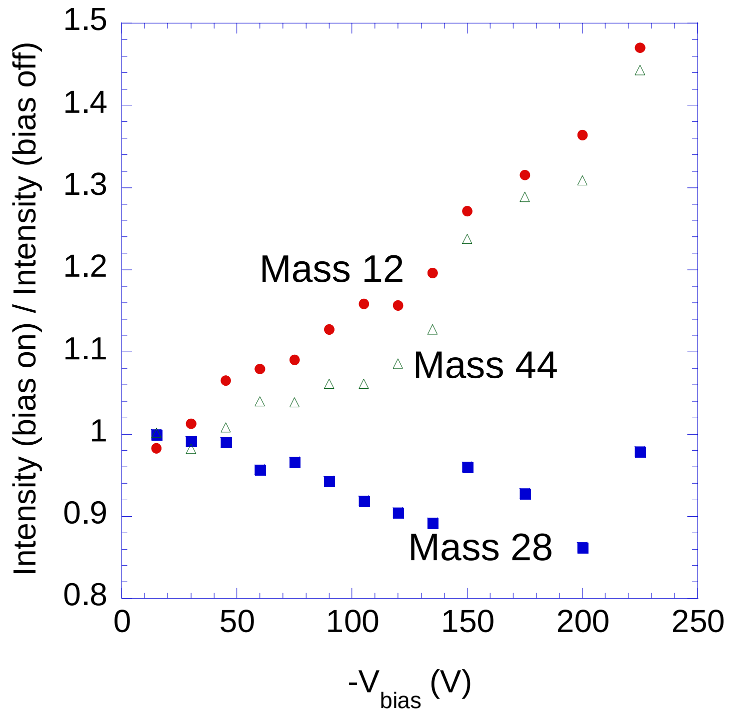
[R.P. Doerner, D.G. Whyte and D.M. Goebel, J. Appl. Phys. 93(2003)5816]



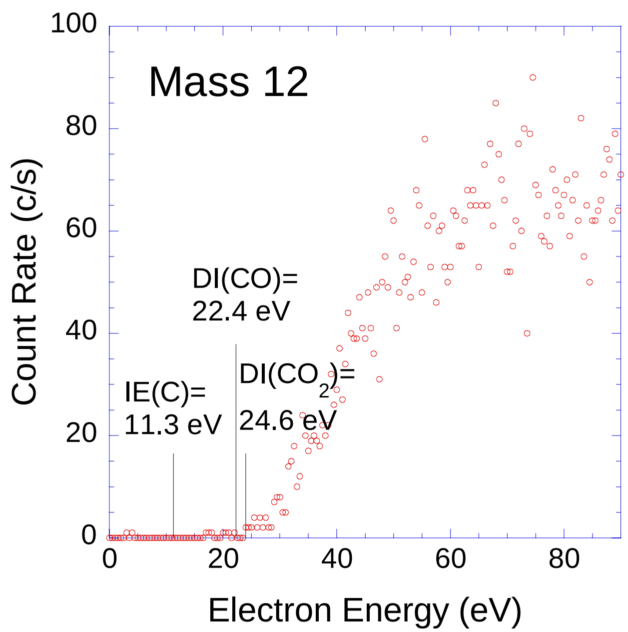
- Chemical erosion of CO is estimated to be within the weight loss error bars at 50 eV
- Chemical erosion of CO is ~independent of incident energy
- Carbon dimer erosion appeared more dominant than the carbon atom sputtering term
- Carbon trimers, etc. were not investigated at the time

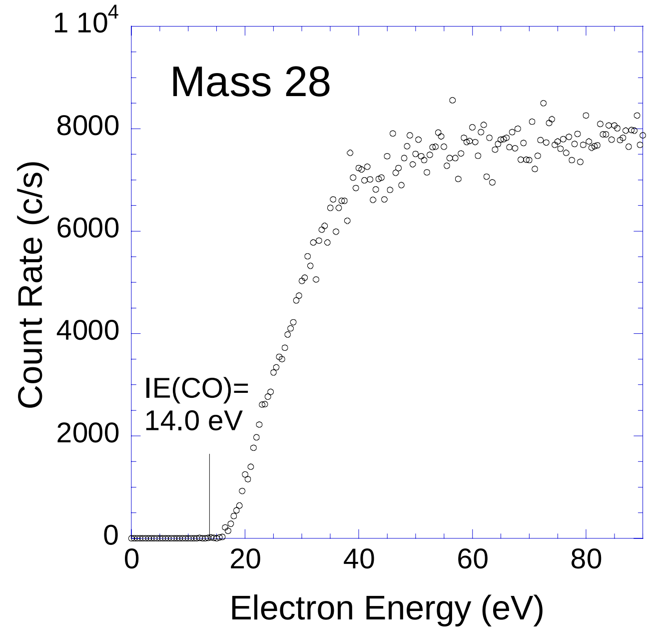
Neutral particle detection with carbon target

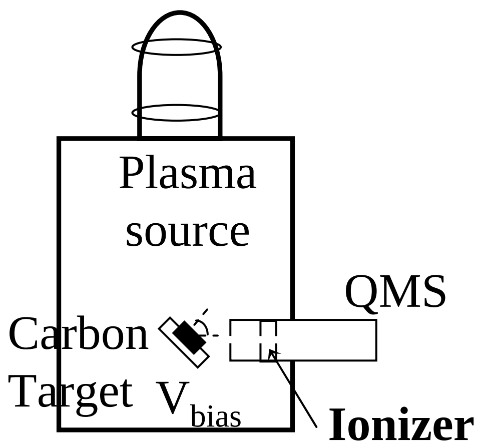




Appearance mass spectroscopy shows that measured mass 12 signal is cracked CO and CO_2







Future plans for neutral sputtered particle detection:

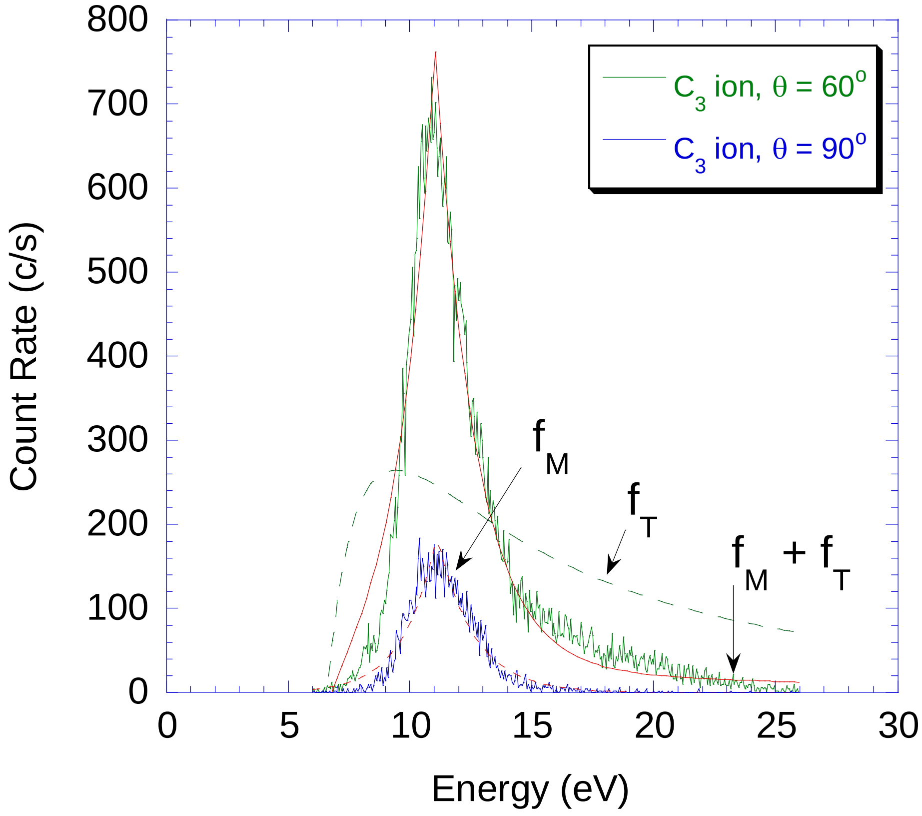
•Set electron energy in ionizer to 15-20 eV.

•Use long-time accumulation and/or lock-in detection to increase signal to noise.

•Upgrade ionizer stage to increase ionization efficiency.

Ion detection -- Carbon cluster sputtering by Xe

High energy tail represents sputtered particle distribution.
Low energy component is nearly thermal, indicating collisional scattering.



Maxwellian:

$f_M = E^{1/2}\, e^{-(E - e\Delta\phi_S)/T}$

Thompson:

$f_T = E/(E+E_b)^3$

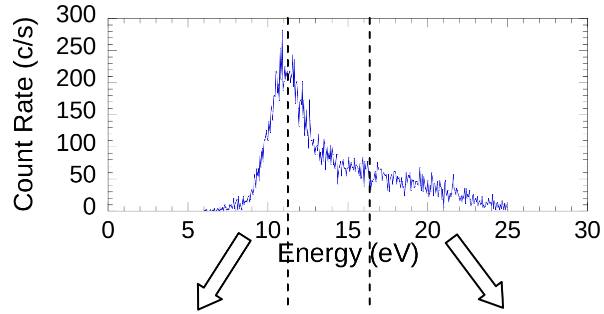
Fits yield

$\Delta\phi_s = 11.0$ V

T = 1.5 eV

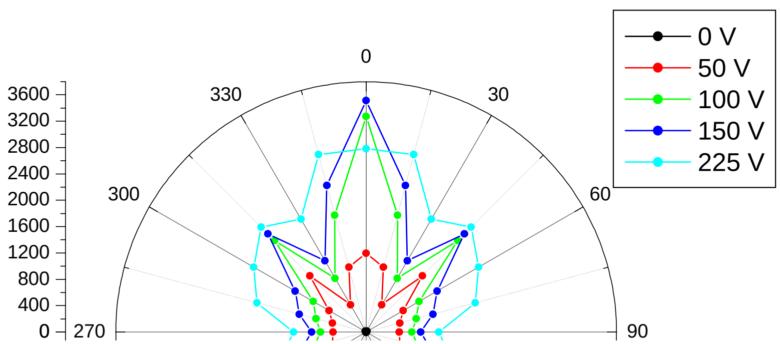
$E_b = 10.0$ eV

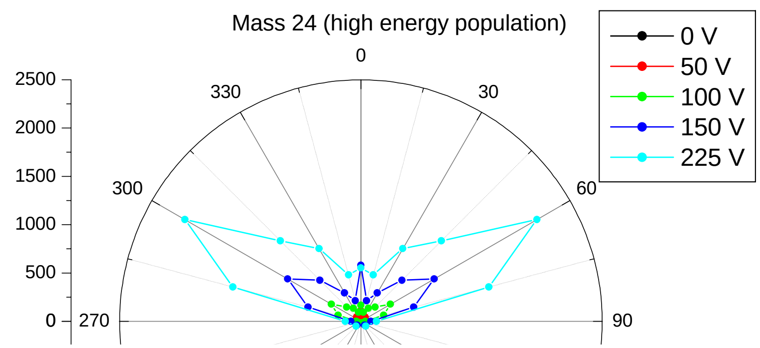
Carbon cluster low- and high-energy angular distributions



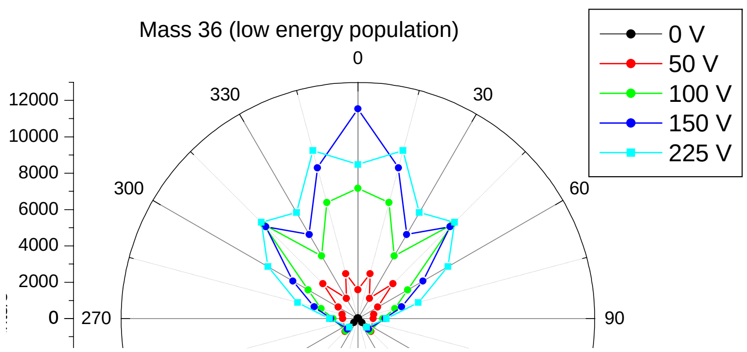
Mass

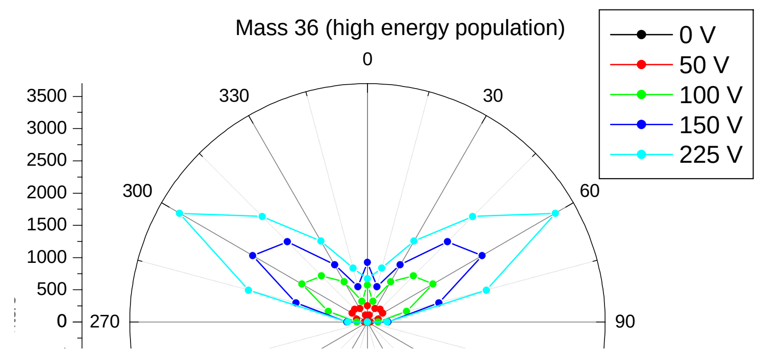
C_2 24





C_3 36





Mo & C Sputtering Summary

- High energy ion signal represents sputtered atoms that are ionized in the plasma. This angular distribution is peaked at $\theta \sim 60^o$.
- Low energy ion signal represents sputtered atoms that have been ionized and elastically scattered.
- Lower-pressure plasmas are needed to reduce the complication of ion-neutral elastic scattering.
- Direct detection of sputtered neutrals is a challenge due oxygen contamination and low ionization efficiency in the QMS. We are in the process of upgrading the ionizing stage.

Behavior of eroded beryllium atoms in PISCES-B

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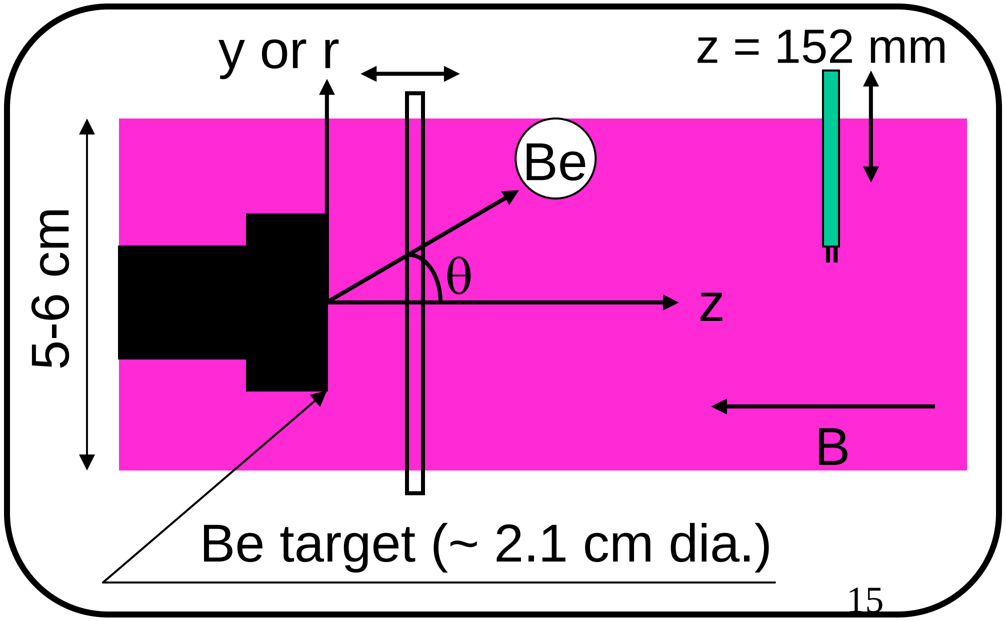
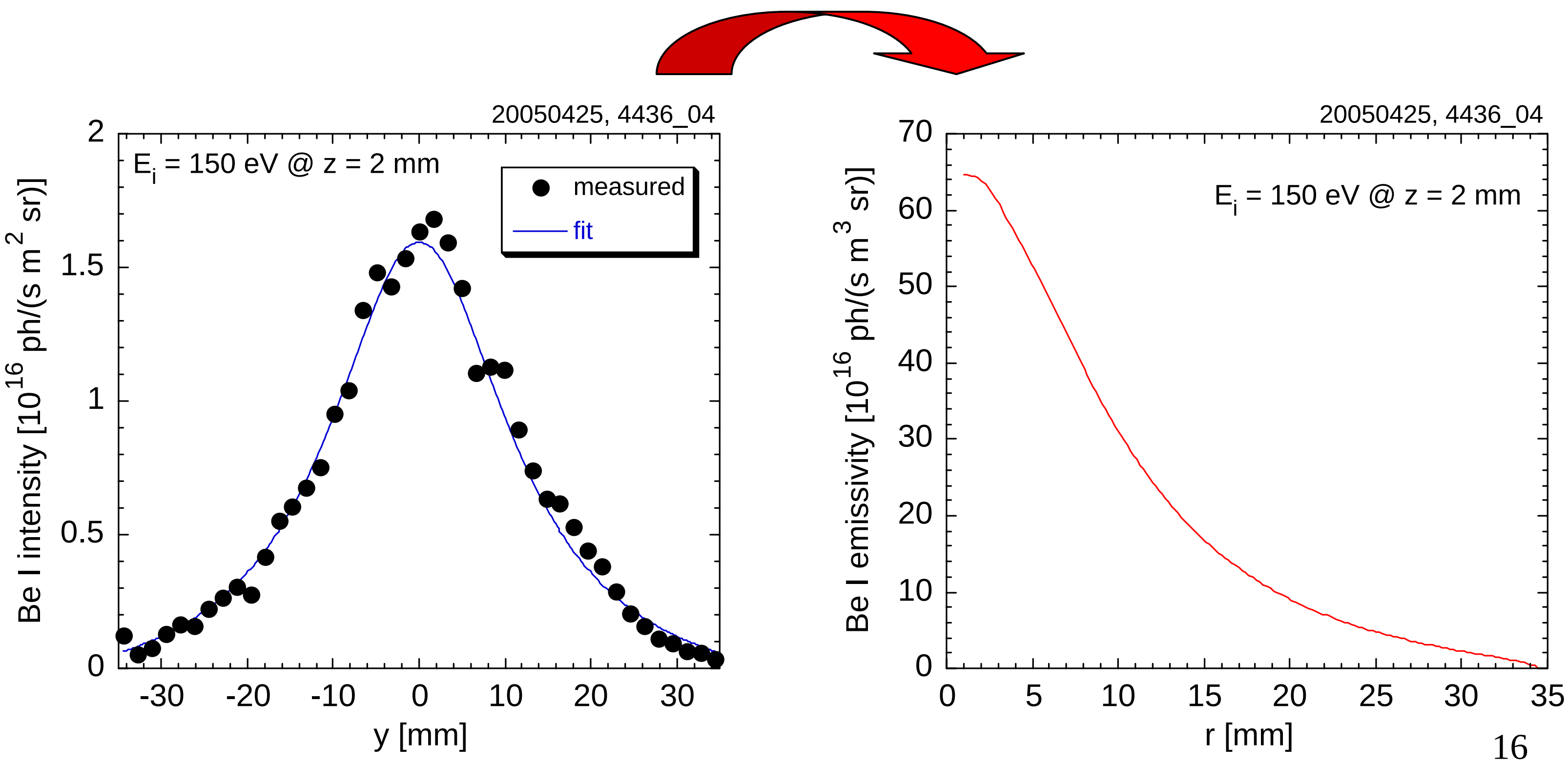
Experimental setup

- Spectroscopy (absolutely calibrated system)
  - The light is guided with a mirror and focused with a lens to the entrance slit of spectrometer equipped with a 2-D CCD camera.
  - Vertical (y) profiles of Be I (2s2p ^1P-2s3d ^1D: 457.3 nm) line intensity emitted from sputtered Be neutrals were measured at several z positions (every 2 mm near the target).
  - Spatial resolution:
    $\Delta z \sim 1$ mm
    $\Delta y \sim 1.64$ mm
- Double probe
  - $n_e \sim 1\text{-}3\times10^{18}$ m^{-3}
  - $T_e \sim 8$ eV
  - $\Gamma_i \sim 1.5\text{-}3\times10^{22}$ $m^{-2}s^{-1}$
  - Flat radial profile



Abel inversion can be applied to derive local emissivity (as a function of radius) from line integrated intensity (as a function of y).

Abel inversion: $$\varepsilon(r) = -\frac{1}{\pi}\int_r^a \frac{dI(y)}{dy}\frac{dy}{\sqrt{y^2 - r^2}}$$

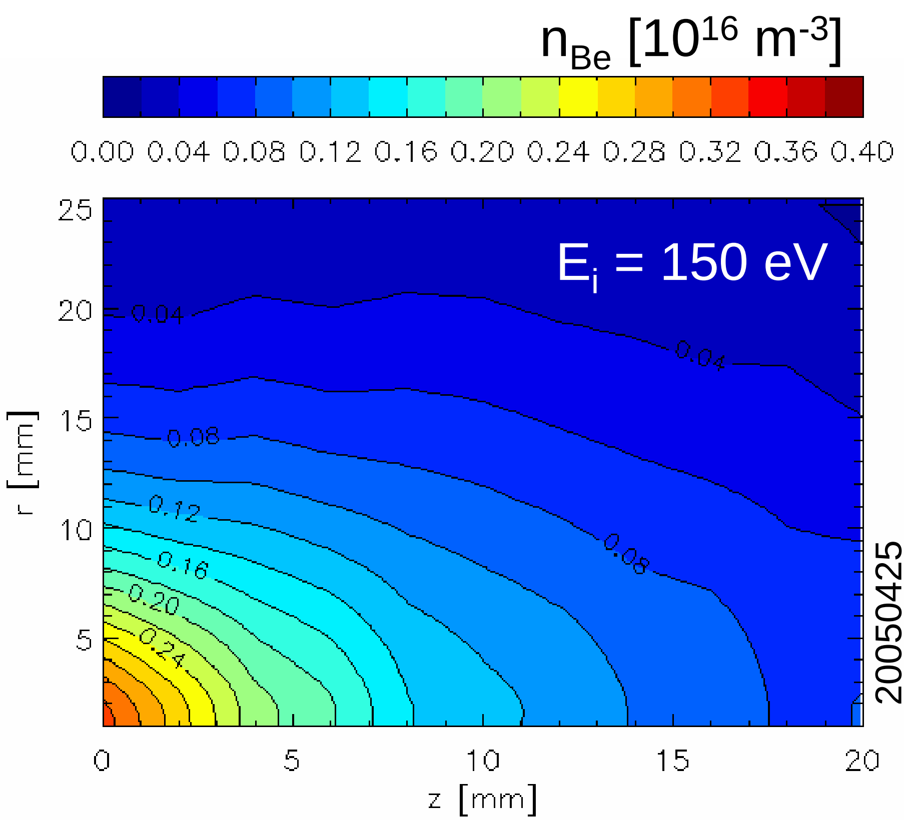


Derivation of local ground state Be density

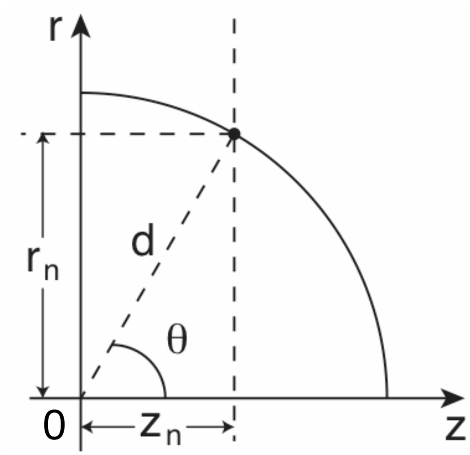
$$\langle \sigma v \rangle_{457.3nm} n_e n_{Be} = 4\pi\varepsilon \Rightarrow n_{Be} = \frac{4\pi\varepsilon}{\langle \sigma v \rangle_{457.3nm} n_e}$$

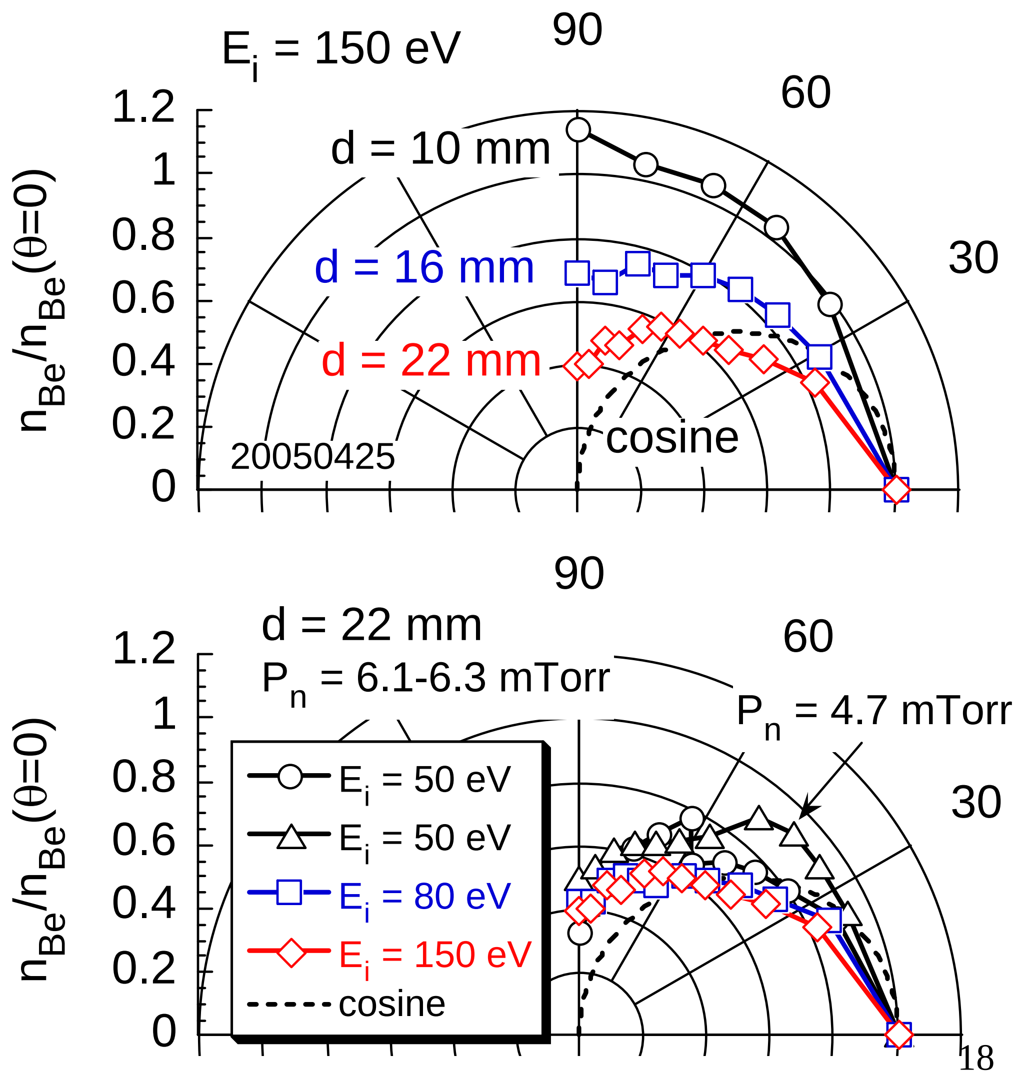
$\langle \sigma v \rangle_{457.3nm}$: Photon emission coefficient [ph m³/s] of Be I line (2s2p ^{1}P-2s3d ^{1}D: 457.3 nm) from ADAS data base

- Note that excitation only from the ground state (2s² ^{1}S) is taken into account.
- There is no information available about a metastable state (2s2p ^{3}P) in the experiment.



Angular distribution does not makedly change from E_i = 50 to 150 eV.



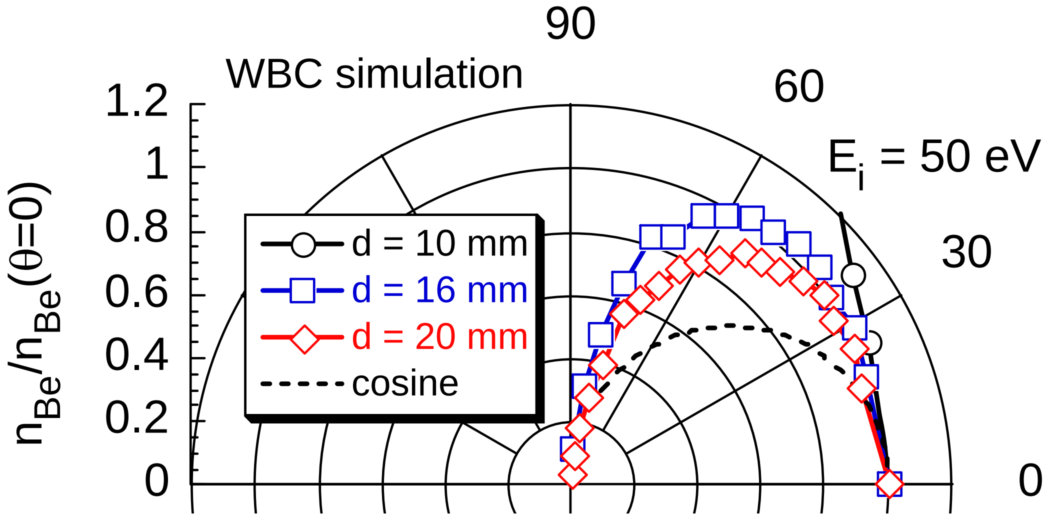


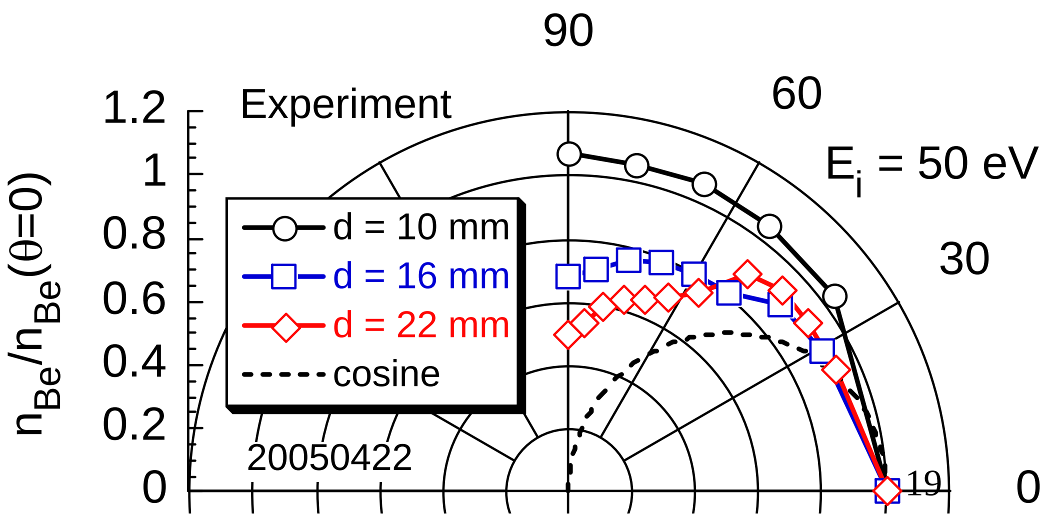
- Distribution at E_i = 50 eV with lower P_n is slightly different from others at θ ~ 30-60 deg.
- Further investigation on effects of P_n is needed.

Differences between modeling and experiment are seen at large angle (θ > 60 deg).

PISCES-B

- WBC monte carlo code simulation (by J.N. Brooks) uses TRIM-predicted cosine angular distribution.
- At larger d, the distribution becomes closer to cosine distribution for point source.
- In experiments, n_{Be} does not become small at large angle (θ > 60 deg.).
  - -- Deviation from cosine distribution?





Summary and conclusion

- Measurement of 2-D profiles of Be I emission and density eroded from Be target has become possible using spectroscopic techniques with the absolutely calibrated system.

- The incident ion energy dependence of angular distribution of eroded Be atoms is small.

- At large angle ($\theta > 60$ deg), the measured angular distribution deviates from the WBC modeling result, where the cosine distribution is employed.

- The measured axial e-folding distance of eroded Be atom density is in good agreement with the WBC modeling.