
# Rutherford Backscattering Spectrometry

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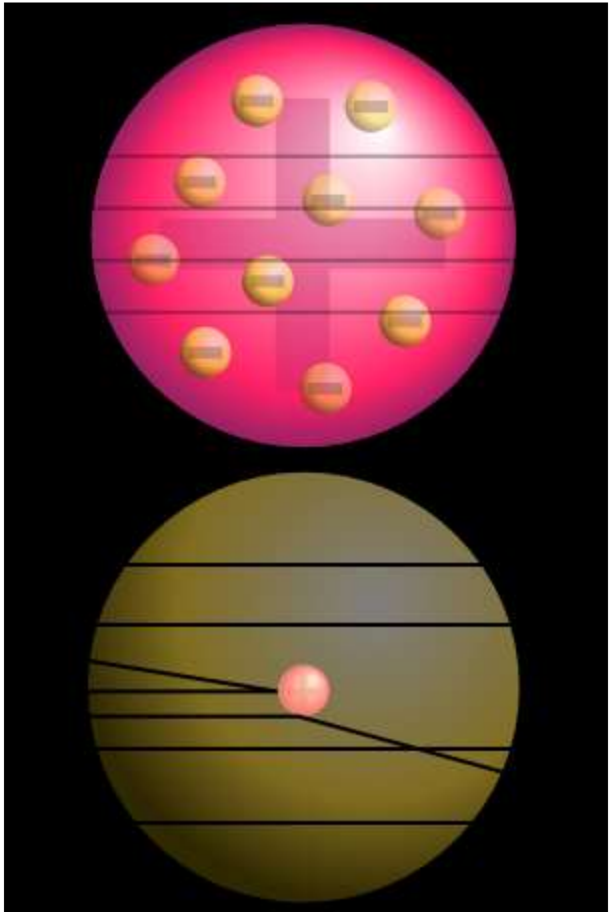
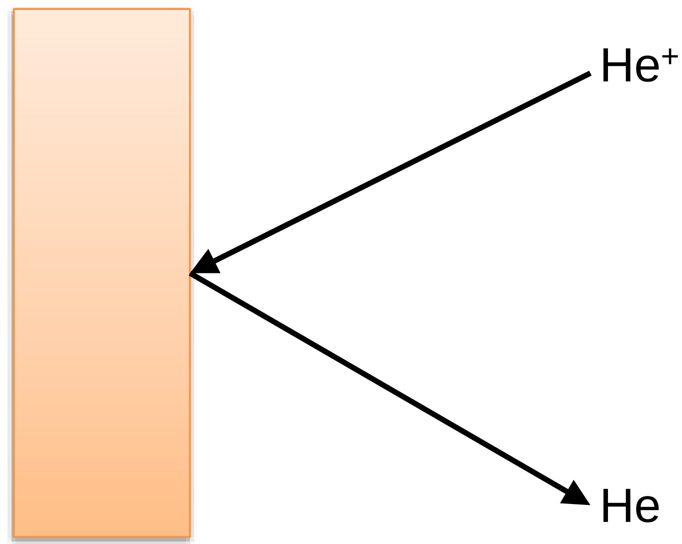
# Geiger-Marsden Experiment



*Top:* Expected results:
alpha particles passing through the plum pudding model of the atom undisturbed.

*Bottom:* Observed results:
a small portion of the particles were deflected, indicating a small, concentrated positive charge.

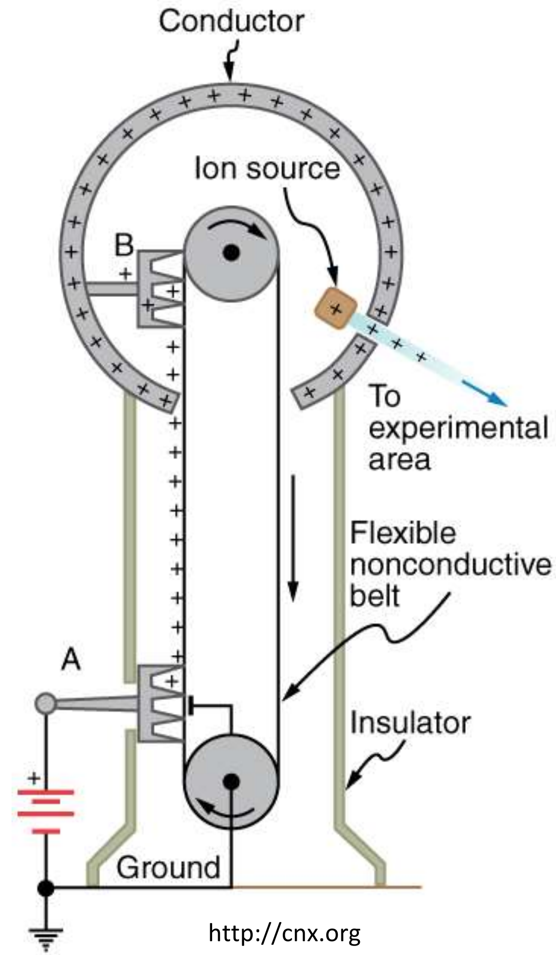
# Rutherford Backscattering Spectrometry




**RBS is an analytical technique where high energy ions (~2 MeV) are scattered from atomic nuclei in a sample. The energy of the back-scattered ions can be measured to give information on sample composition as a function of depth.**

# Van de Graaff accelerator

http://archive.thedailystar.net/newDesign/print_news.php?nid=73473




http://cnx.org

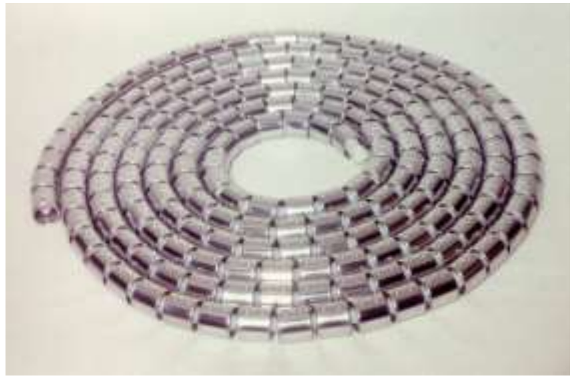
## 3 MeV Van de Graaff accelerator

beam size $\Phi$1-3 mm
flat sample
can be rotated

# Rutherford Backscattering Spectrometry

## 3 MeV Pelletron accelerator

beam size $\Phi$1-3 mm
flat sample
can be rotated



# NEC Pelletron

Pelletron system consists of

- **Ionization chamber**
- Acceleration tube
- Focusing quadrupole
- Steering magnet
- RBS end station

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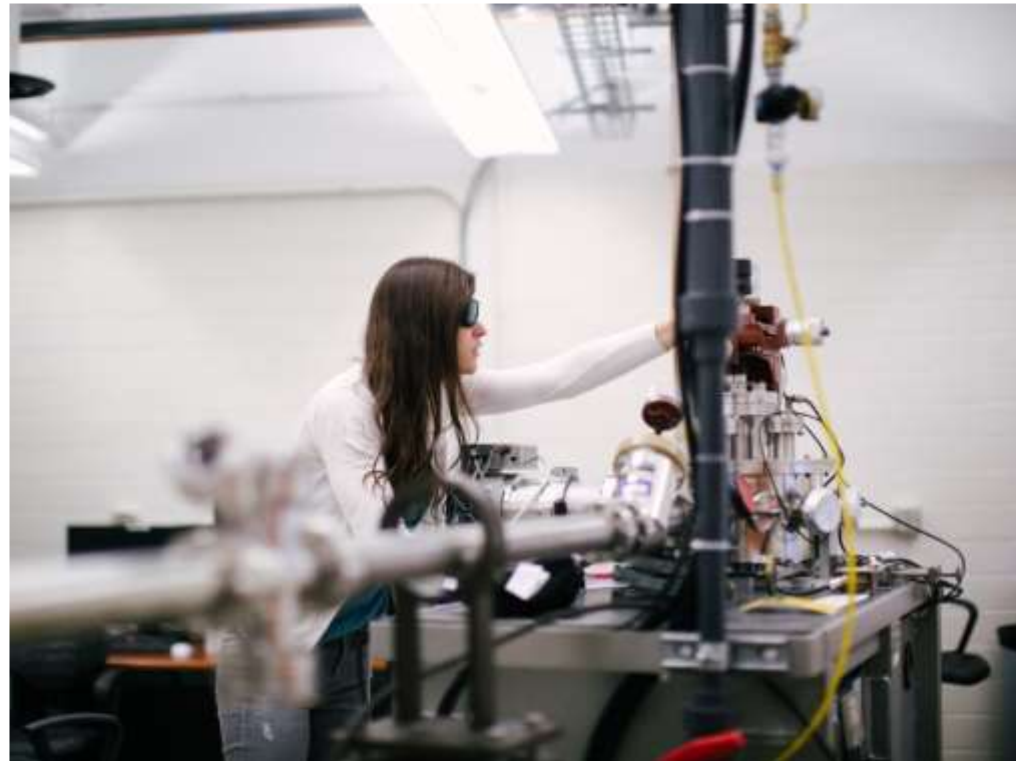
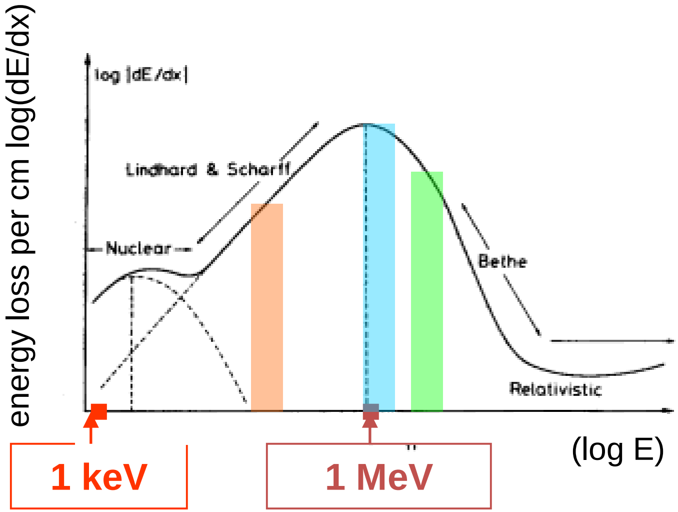
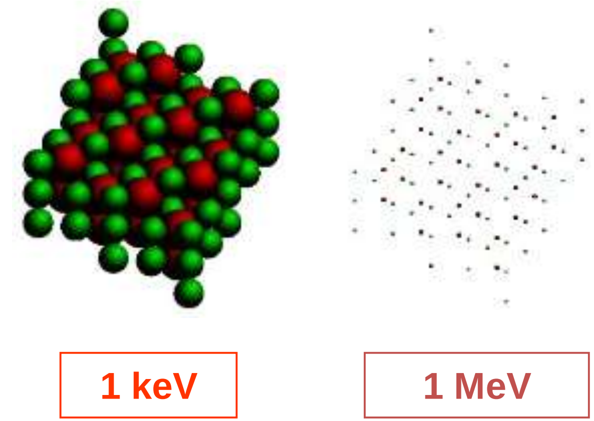


# Primary Beam Energy

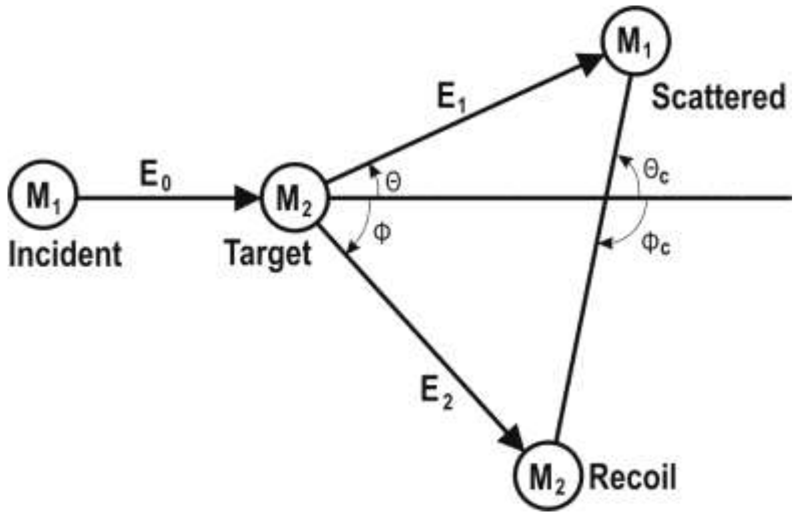



thin film projected on to a plane: **atoms/cm²**

$$(Nt)[at/cm^2] = N[at/cm^3] * t[cm]$$

**Figure after W.-K. Chu, J. W. Mayer, and M.-A. Nicolet, *Backscattering Spectrometry* (Academic Press, New York, 1978).**



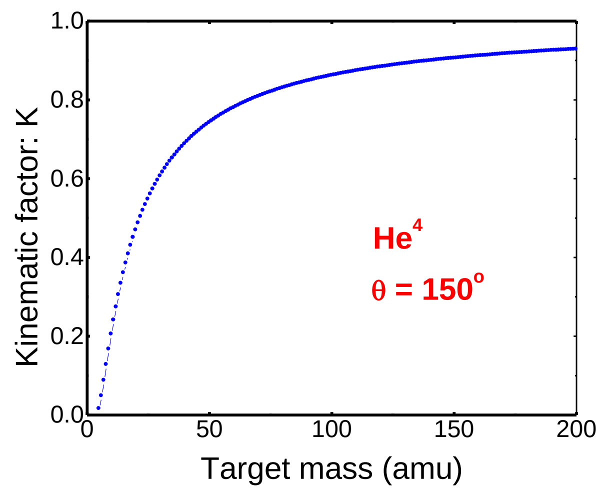

**Elastic Scattering**

$$M_1 v_o^2 = M_1 v_1^2 + M_2 v_2^2$$

$$M_1 \vec{v}_o = M_1 \vec{v}_1 + M_2 \vec{v}_2$$

$$E_1 = KE_o$$

$$K = \left( \frac{\sqrt{M_t^2 - M_i^2 \sin^2\theta} + M_i \cos\theta}{M_i + M_t} \right)^2$$

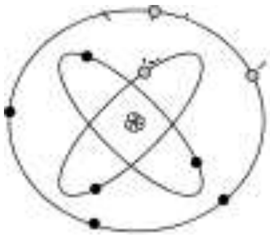


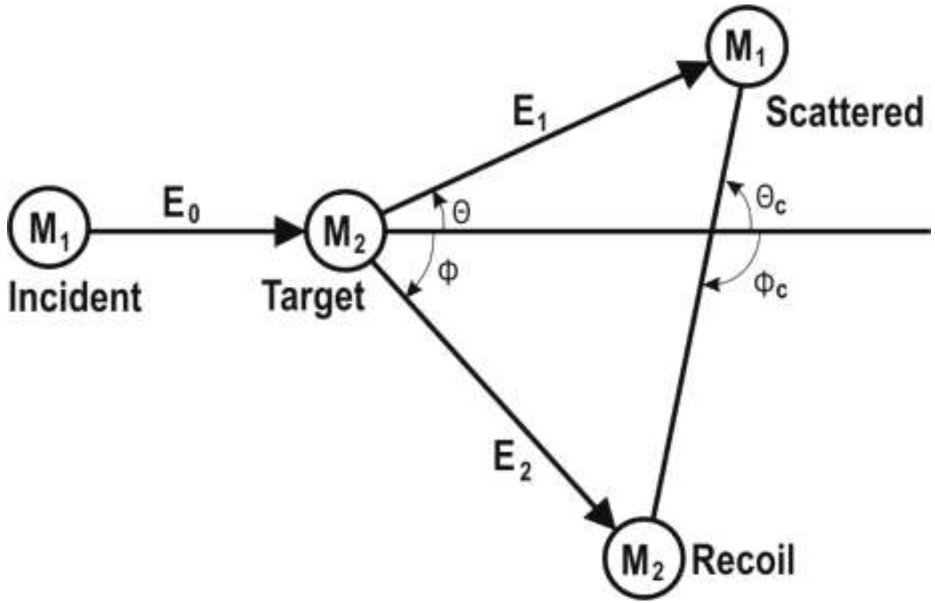

$M_1 < M_2$, $0 \le \theta \le 180^o$

$0 \le \Phi \le 90^o$

RBS: He backscatters from $M_2 > 4$

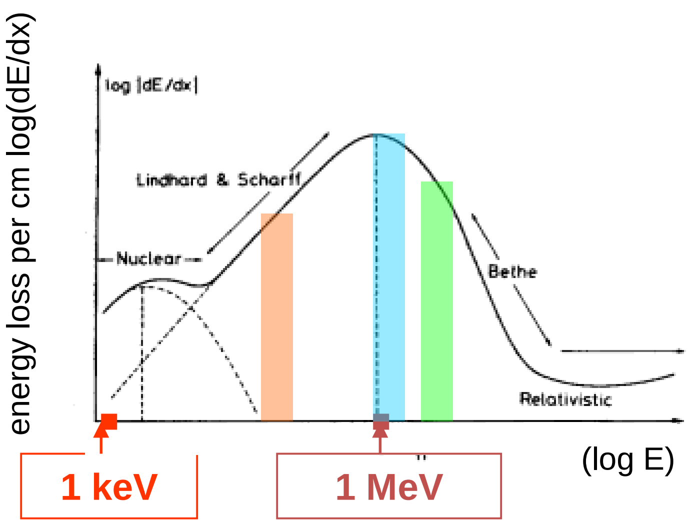
# Rutherford Scattering Cross Section






Coulomb interaction between the nuclei:
exact expression -> quantitative method

$$\sigma_R(E,\theta) \propto \left(\frac{Z_1 Z_2}{4E}\right)^2 \left[\sin^{-4}\left(\frac{\theta}{2}\right) - 2\left(\frac{M_1}{M_2}\right)\right] \propto \left(\frac{Z_2}{E}\right)^2$$



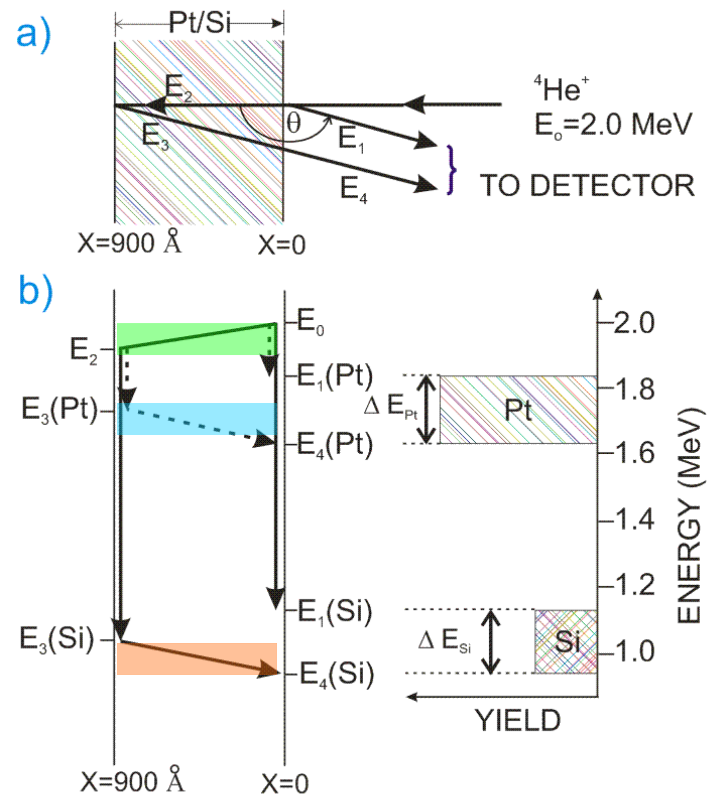
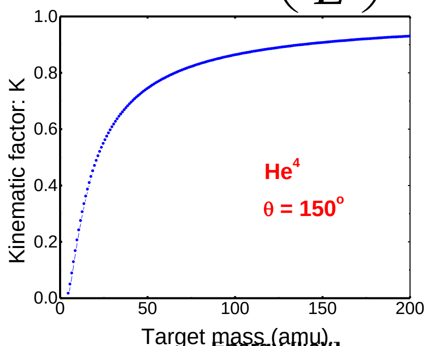



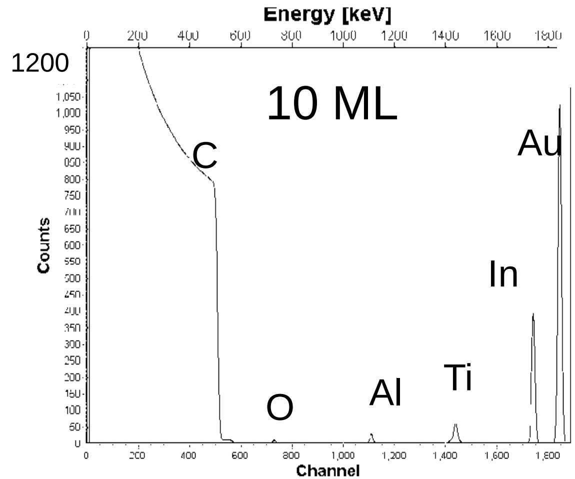

Figure after W.-K. Chu, J. W. Mayer, and M.-A. Nicolet, *Backscattering Spectrometry* (Academic Press, New York, 1978).

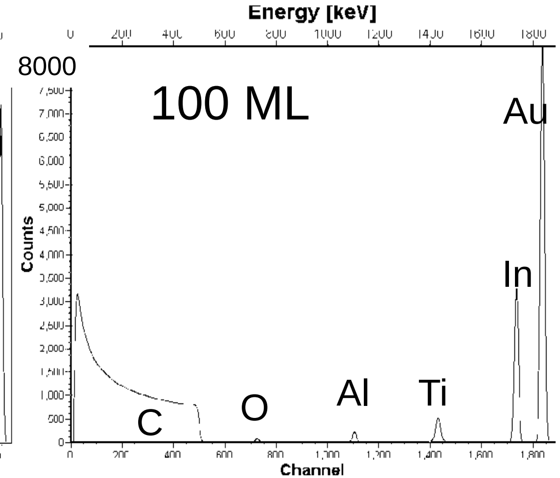
# hypothetical alloy $Au_{0.2}In_{0.2}Ti_{0.2}Al_{0.2}O_{0.2}/C$

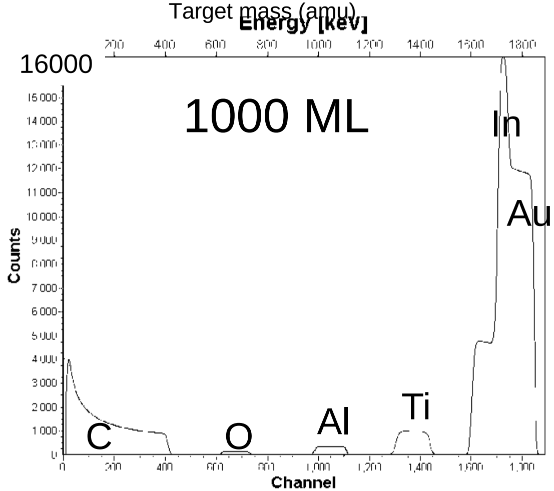
## Element (Z,M): O(8,16), Al(13,27), Ti(22,48), In(49,115), Au(79,197)

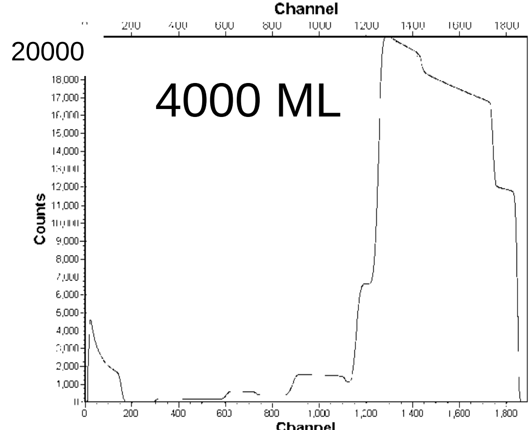
$$\sigma_R(E,\theta) \propto \left(\frac{Z_2}{E}\right)^2$$

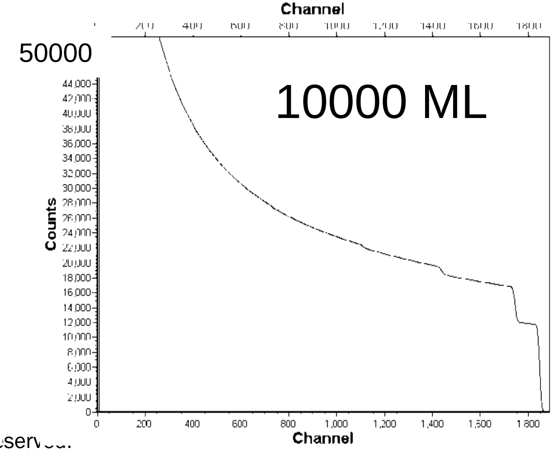


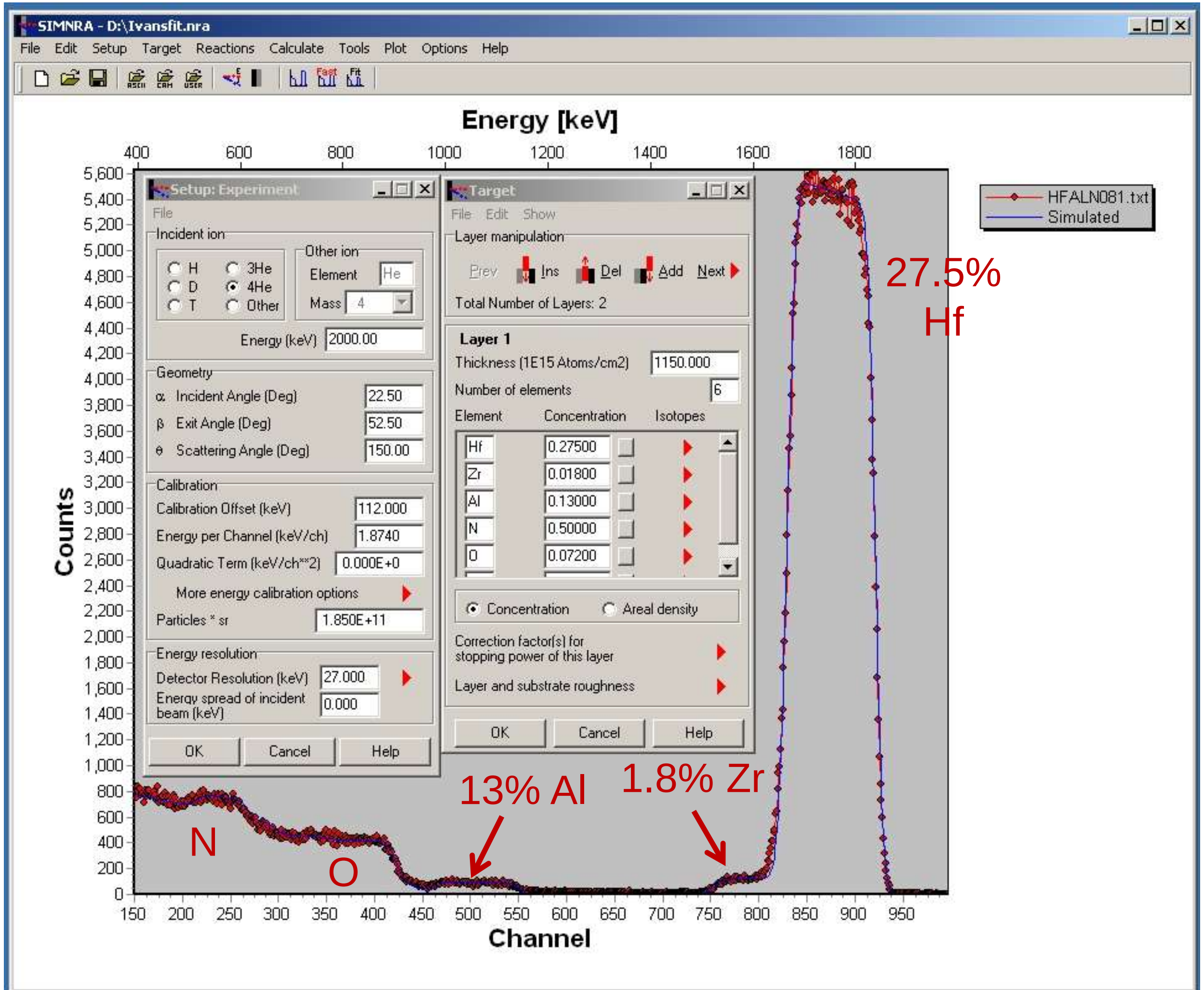



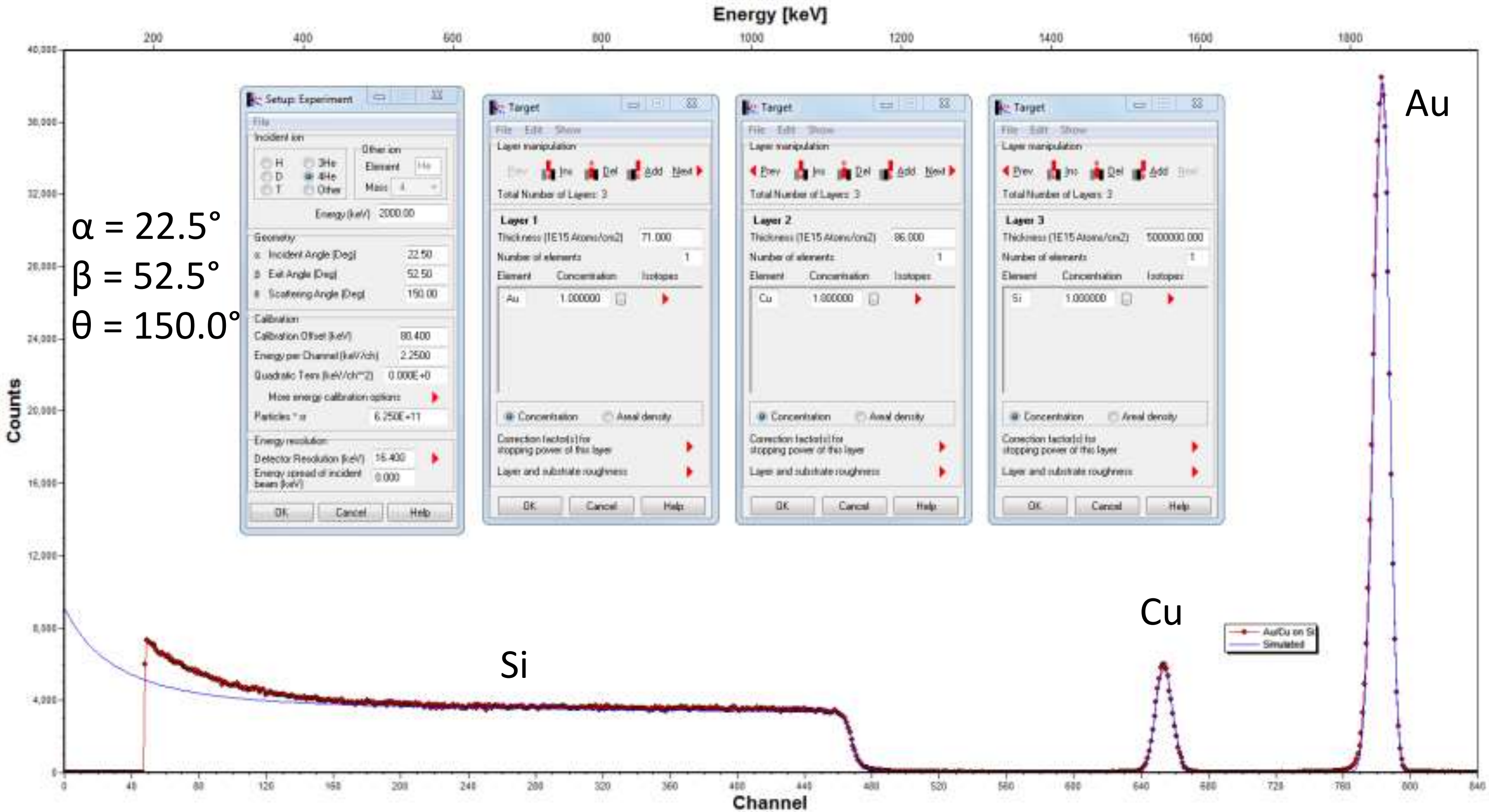



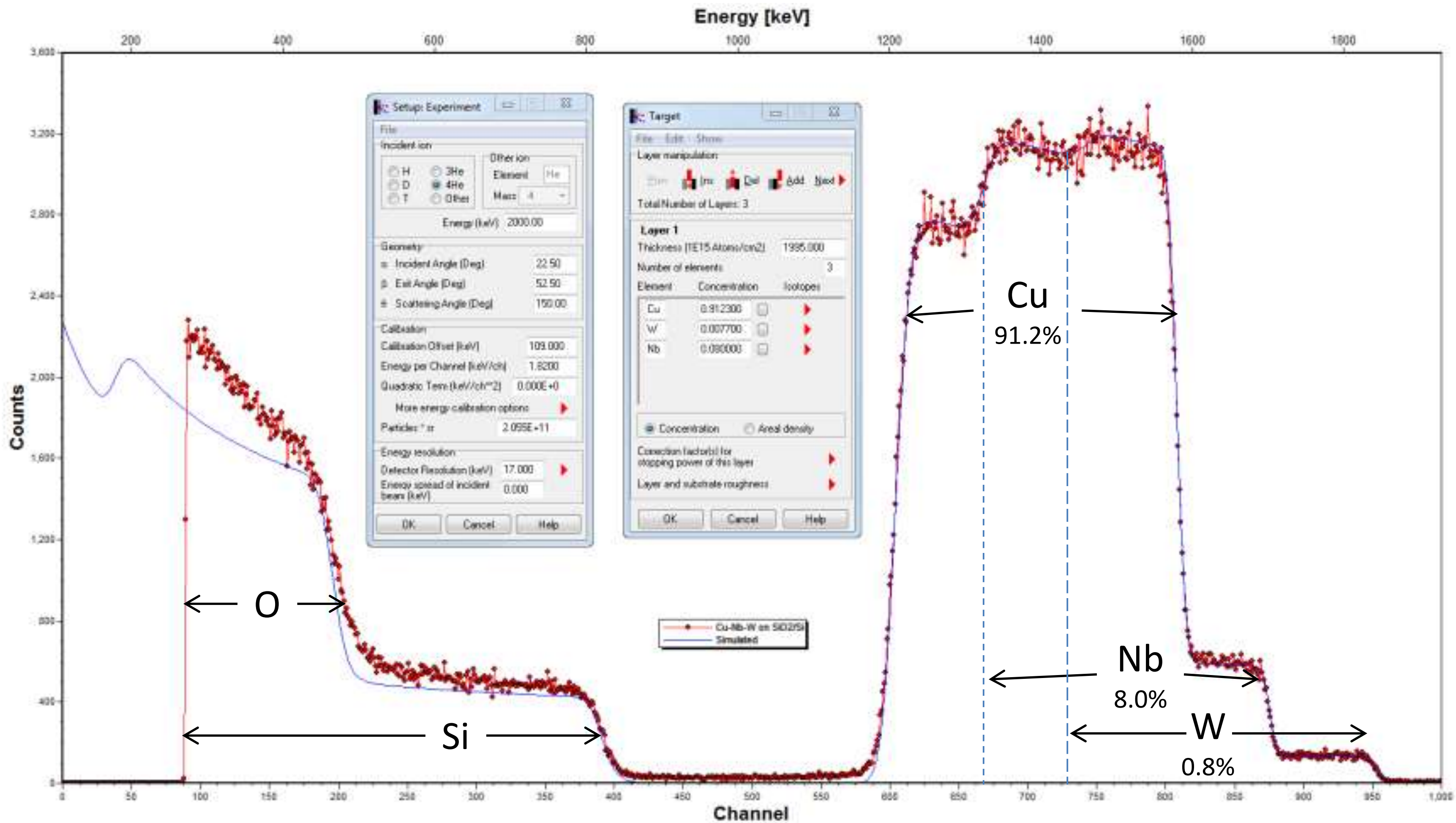
# SIMNRA Simulation Program for RBS and ERD



# Calibration Sample



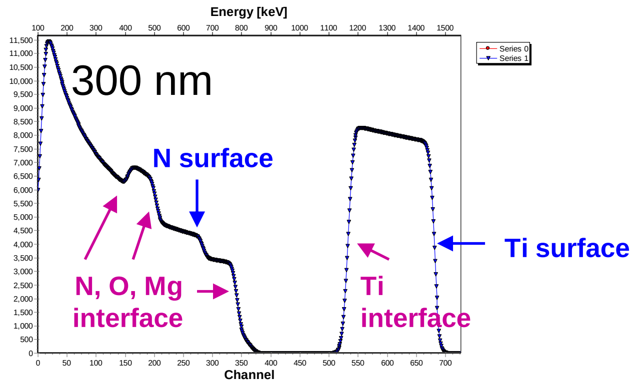
# Cu-Nb-W Alloy on $SiO_2$/Si

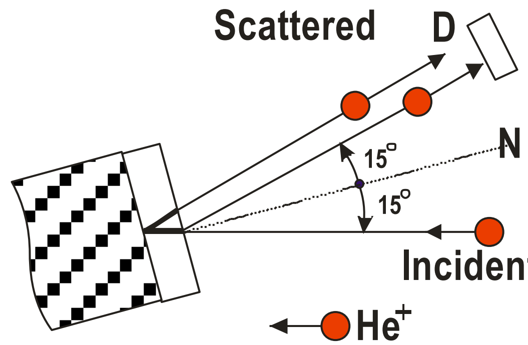


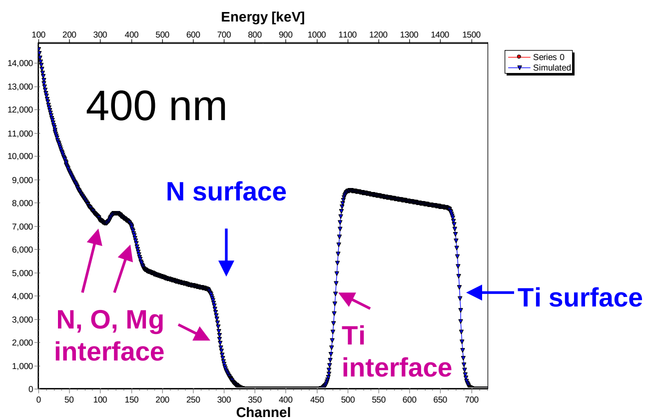

Courtesy N. Vo and R.S. Averback

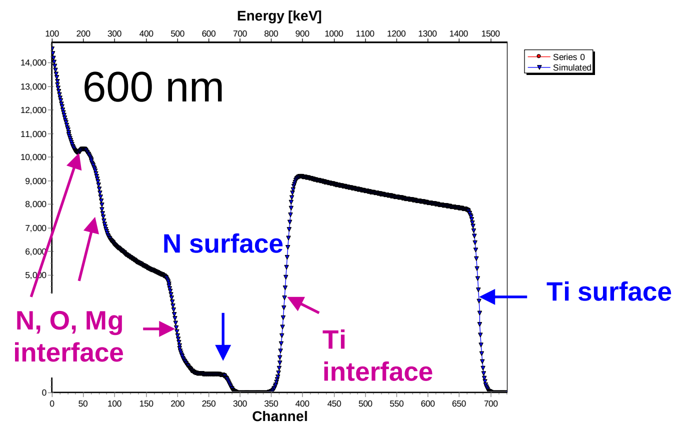
# Thickness Effects

## TiN/MgO



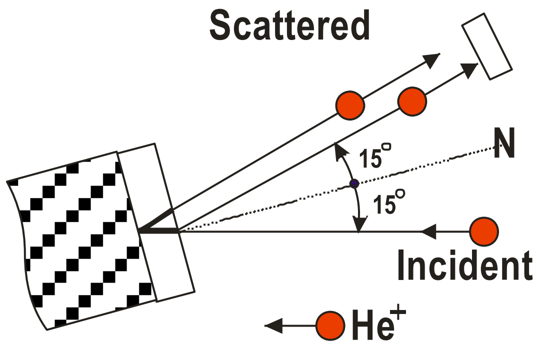



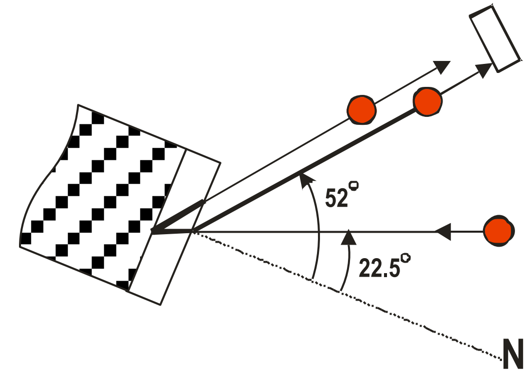



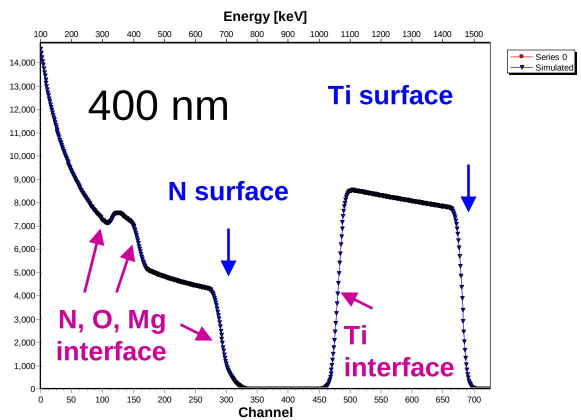



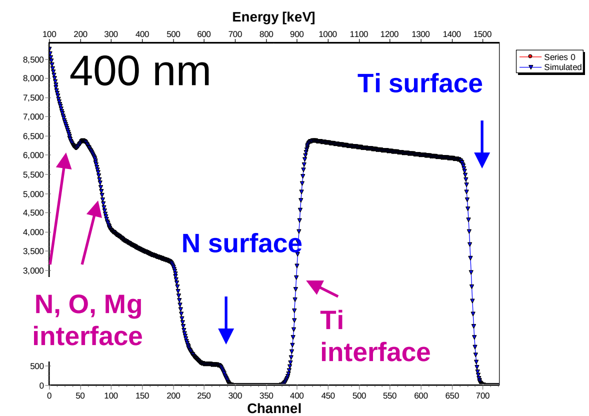
# Incident Angle Effects

## TiN/MgO



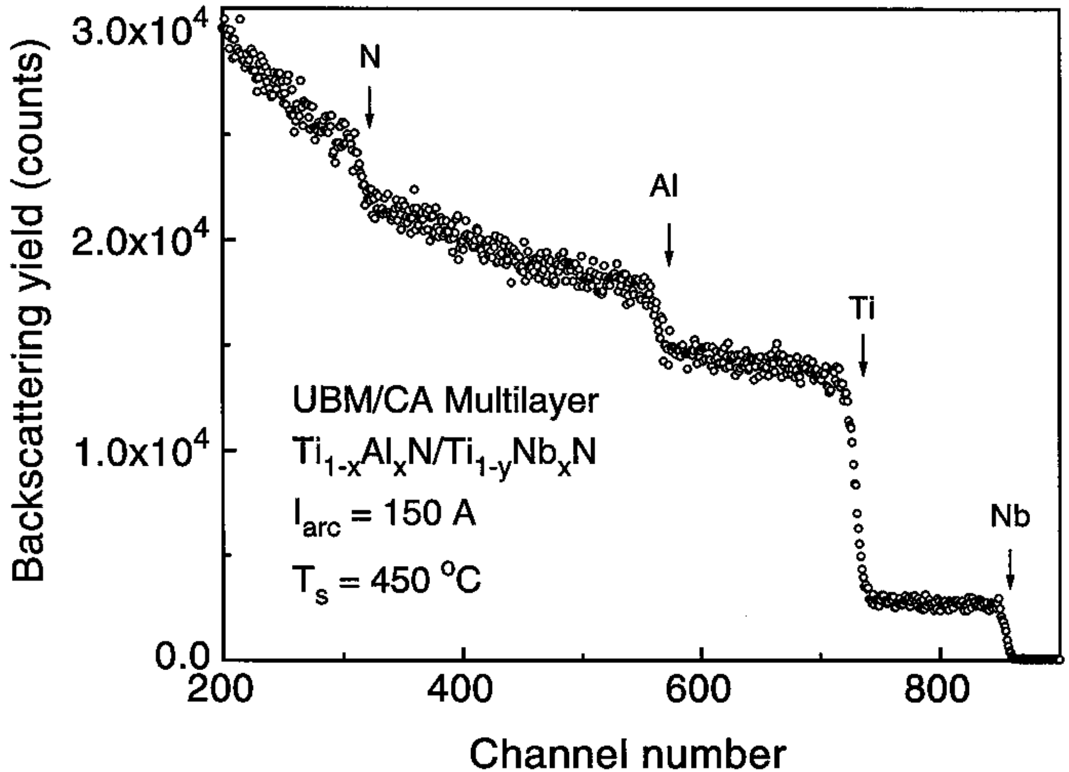




Surface peaks do not change position with incident angle

# Example: Average Composition

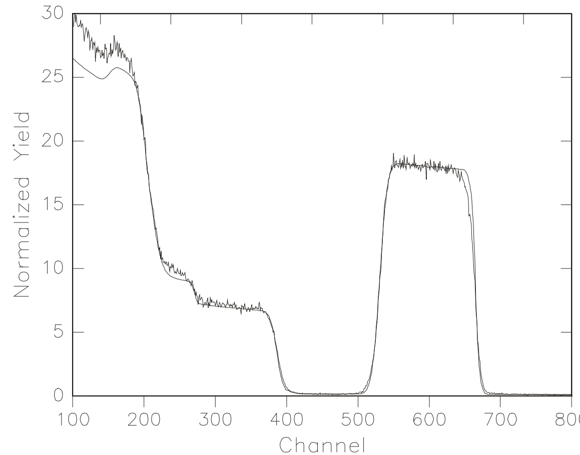



**I. Petrov, P. Losbichler, J. E. Greene, W.-D. Münz, T. Hurkmans, and T. Trinh, *Thin Solid Films,* 302 179 (1997)**

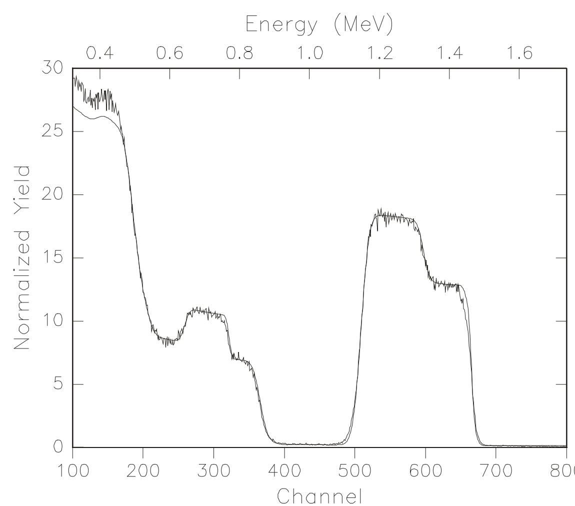
# RBS: Oxidation Behavior

## $TiN/SiO_2$

As-deposited




Annealed in atmosphere for 12 min at $T_a$ = 600 °C

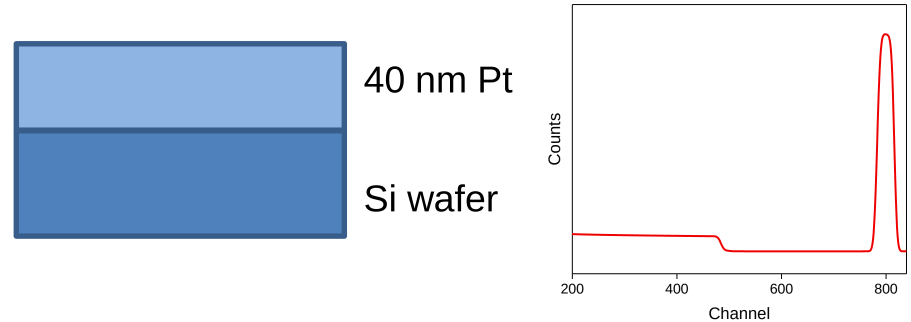


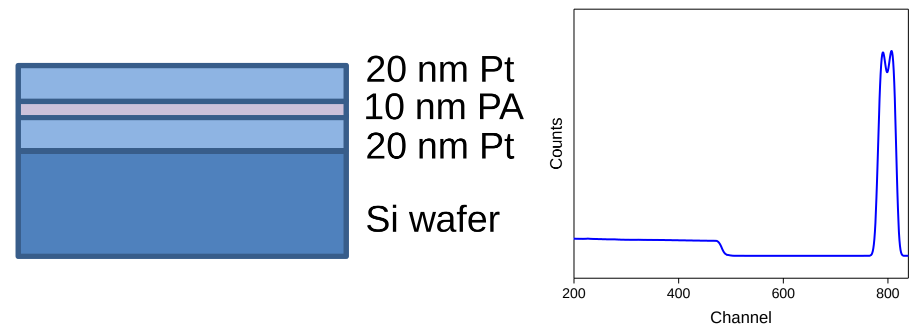

Experimental spectra and simulated spectra by RUMP

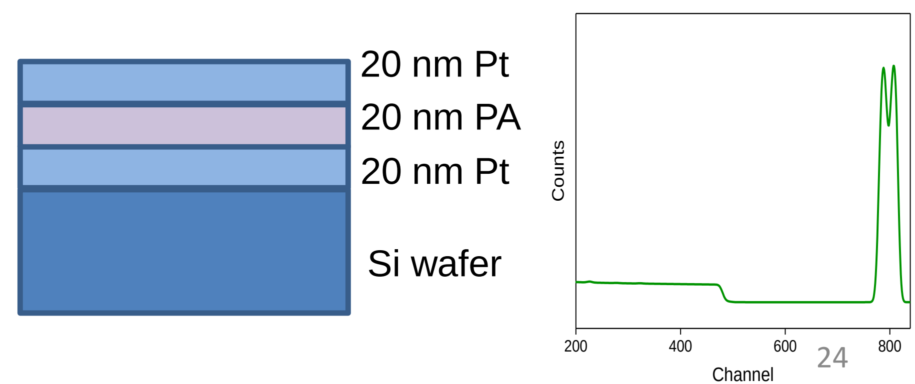
# Areal mass density by RBS

- Free-standing polyamide films are too thin to give sufficient signal in the RBS.

- Use the added stopping power of the polymer to split the Pt peak in the RBS spectrum.

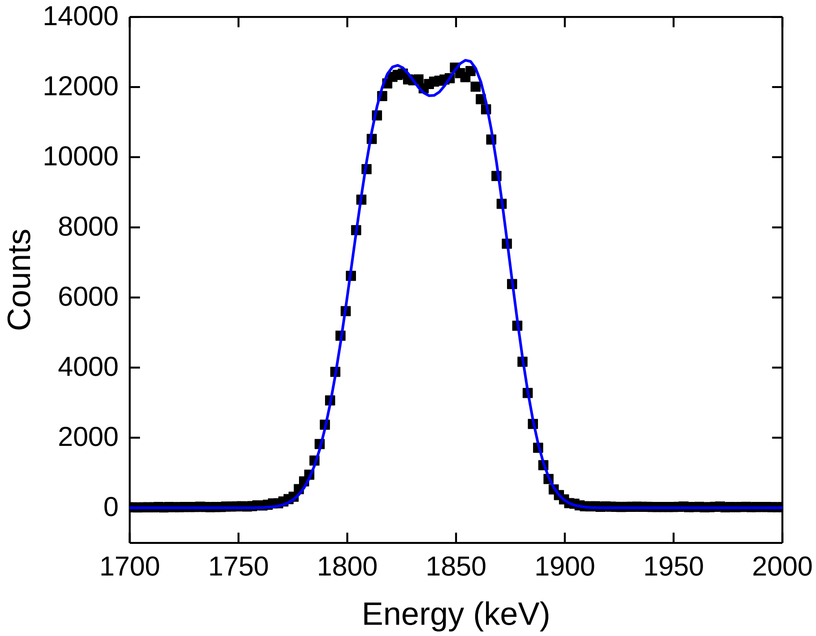


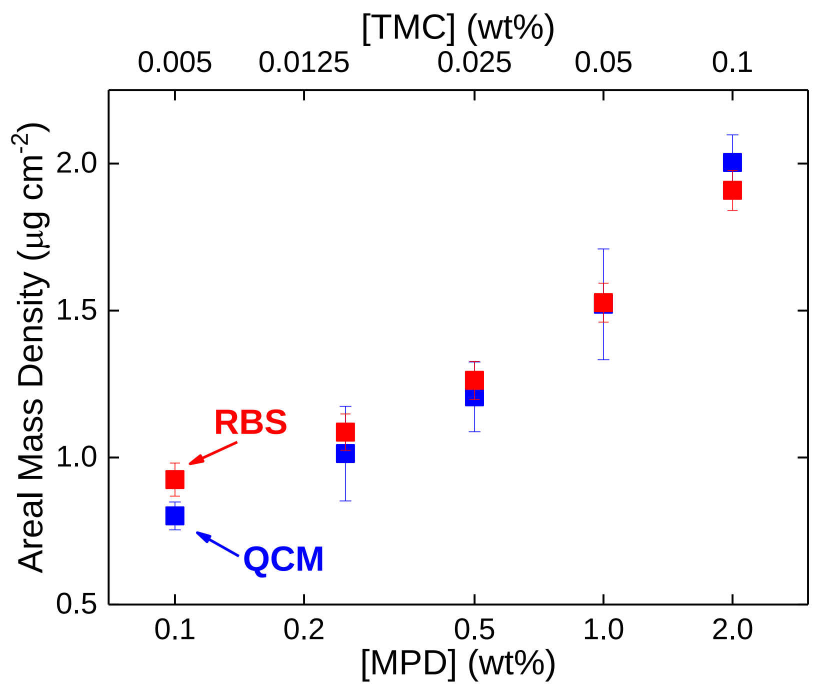



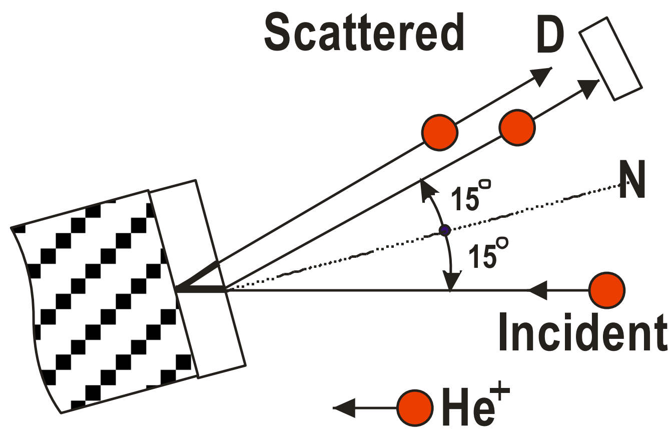
# Areal mass density by RBS

0.005 wt% TMC, 0.1 wt % MPD



# RBS Summary




- Quantitative technique for elemental composition
- Requires flat samples; beam size $\Phi$1-3 mm
- Non-destructive
- Detection limit varies from 0.1 to $10^{-6}$, depending on Z
    - optimum for heavy elements in/on light matrix, e.g. Ta/Si, Au/C…
- Depth information from monolayers to 1 $\mu$m

# Optimizing Simultaneous PIXE and RBS Capabilities

**Thomas J. Pollock**[1], Robert White[2]

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Pollock@pelletron.com
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Robert.White@nrel.gov

National Electrostatics Corp.

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