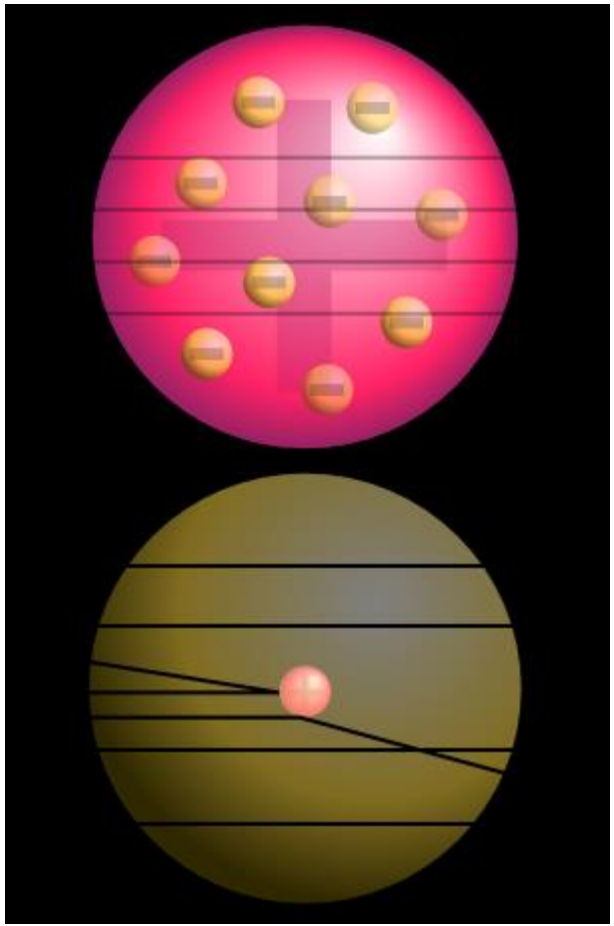
Rutherford Backscattering Spectrometry

Timothy P. Spila, Ph.D.
Sr. Research Scientist

Materials Research Laboratory
MRL.Illinois.edu
University of Illinois at Urbana-Champaign

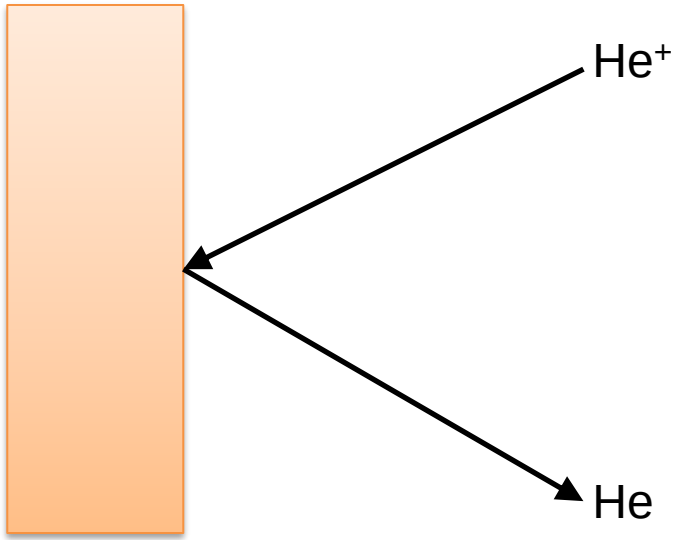
Geiger-Marsden Experiment



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.

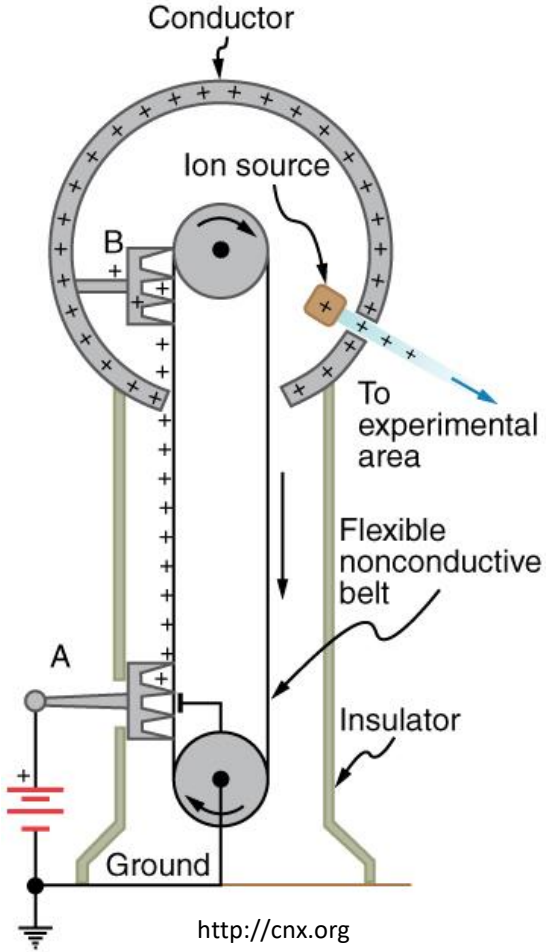
Rutherford Backscattering Spectrometry



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

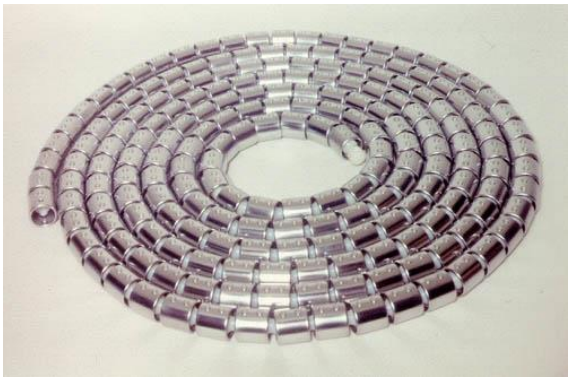


http://cnx.org

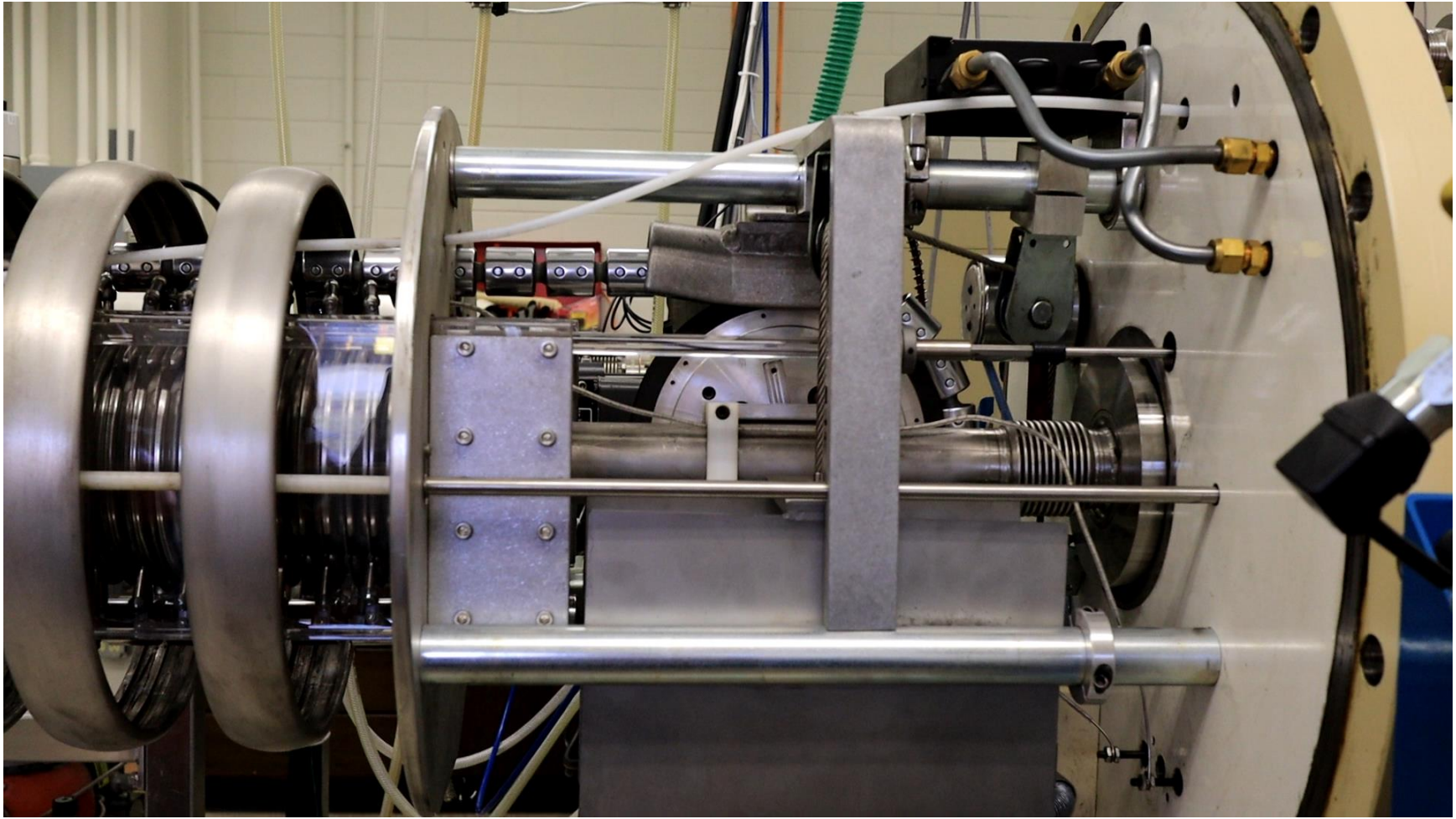
Rutherford Backscattering Spectrometry

3 MeV Pelletron accelerator

beam size Φ1-3 mm
flat sample
can be rotated



NEC Pelletron



NEC Pelletron

Pelletron system consists of

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

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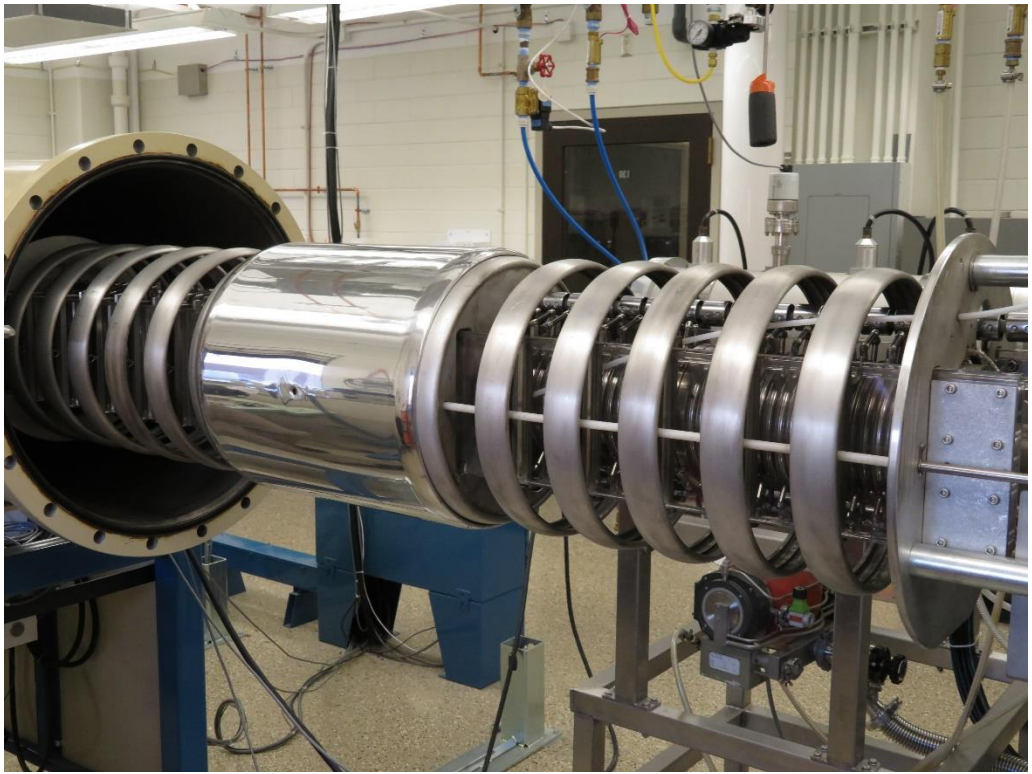

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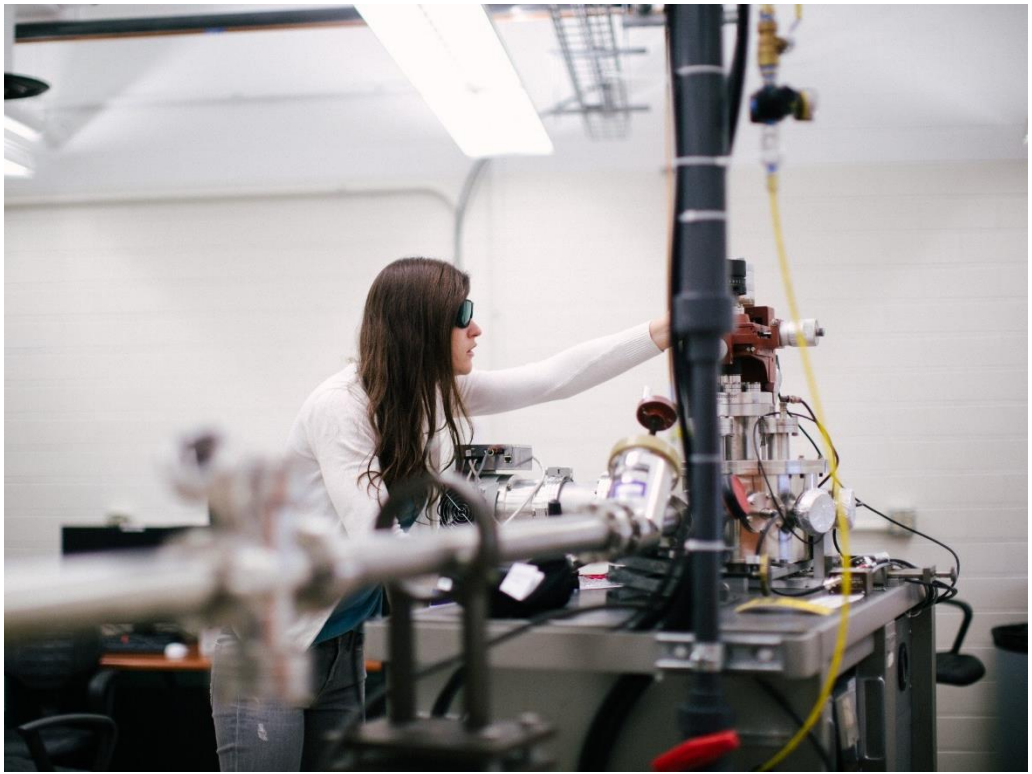
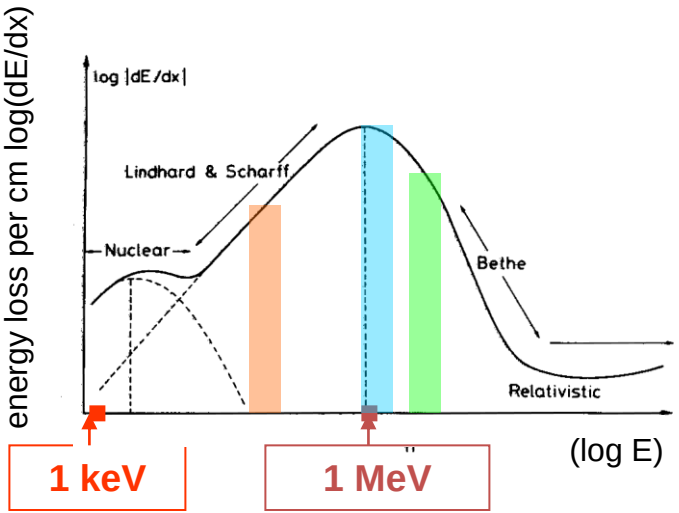
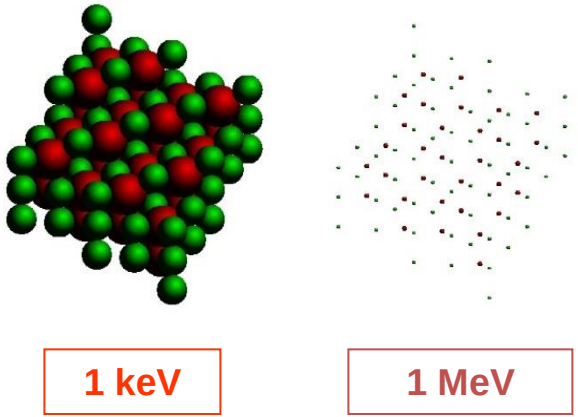


Primary Beam Energy



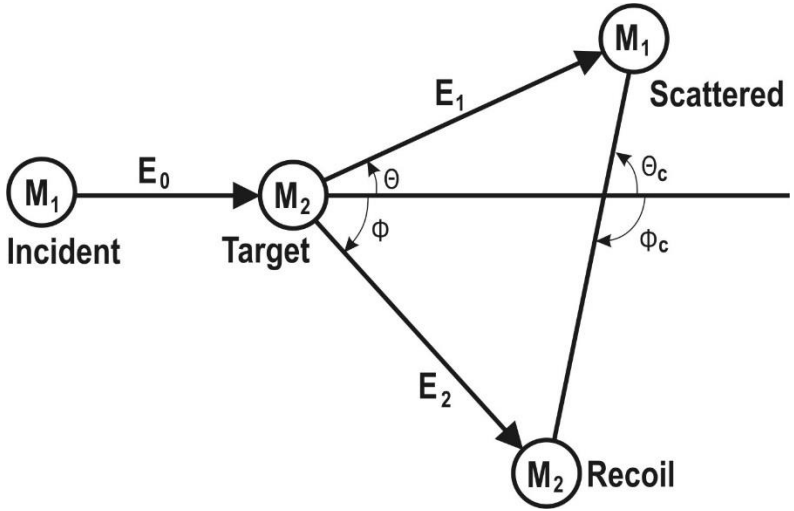


thin film projected on to a plane: **atoms/cm^2**

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

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

Elastic Two-Body Collision



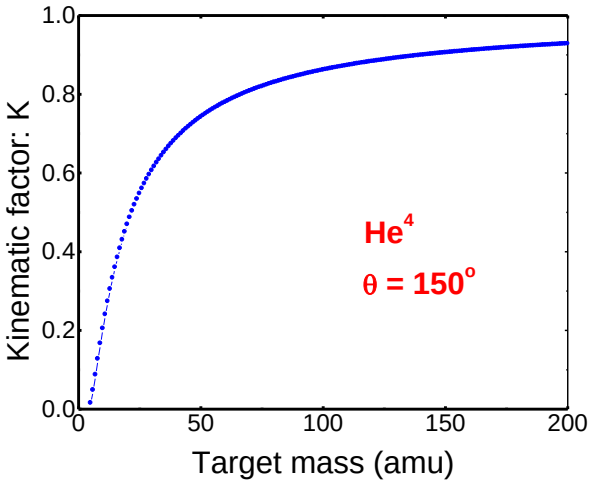
Elastic Scattering

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

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

$$E_1 = KE_o$$

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

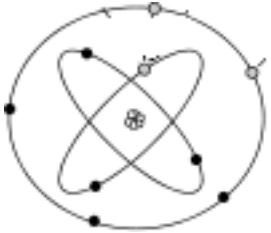


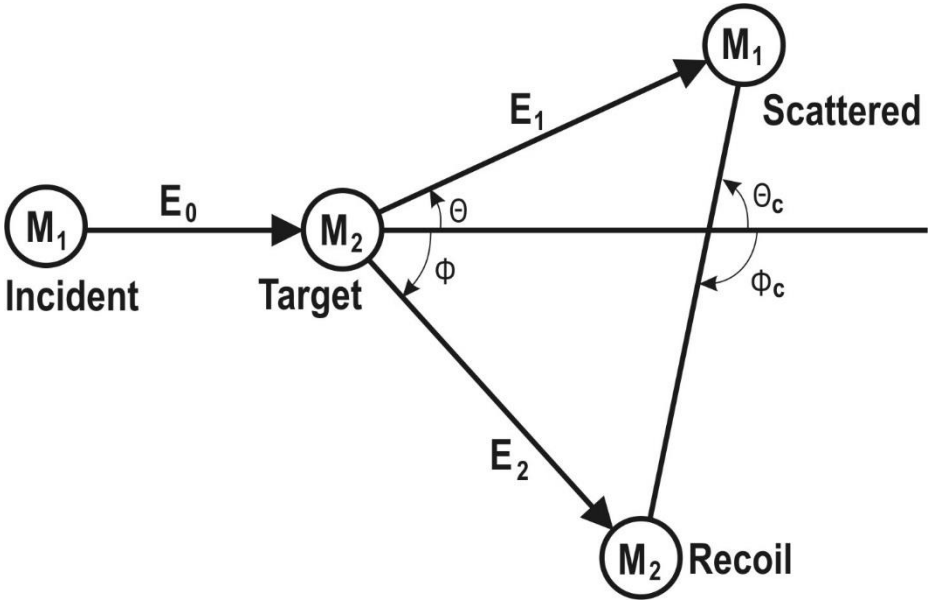
$M_1 < M_2$, $0 \le \theta \le 180^o$

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

RBS: He backscatters from $M_2 > 4$

Rutherford Scattering Cross Section

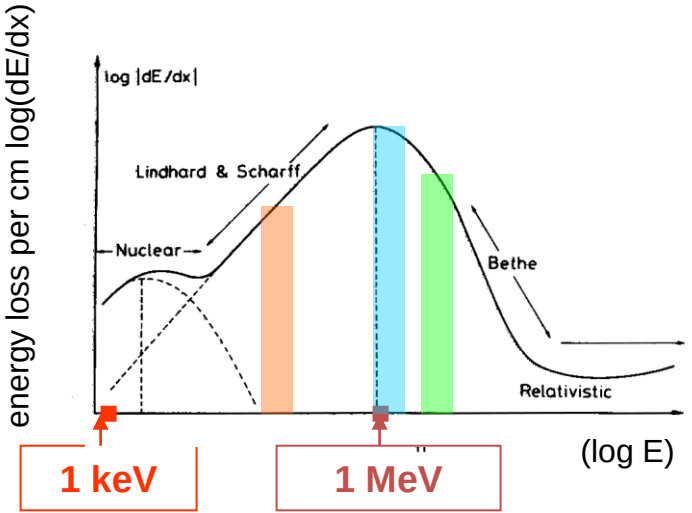




Coulomb interaction between the nuclei:
exact expression -> quantitative method

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

Electron Stopping



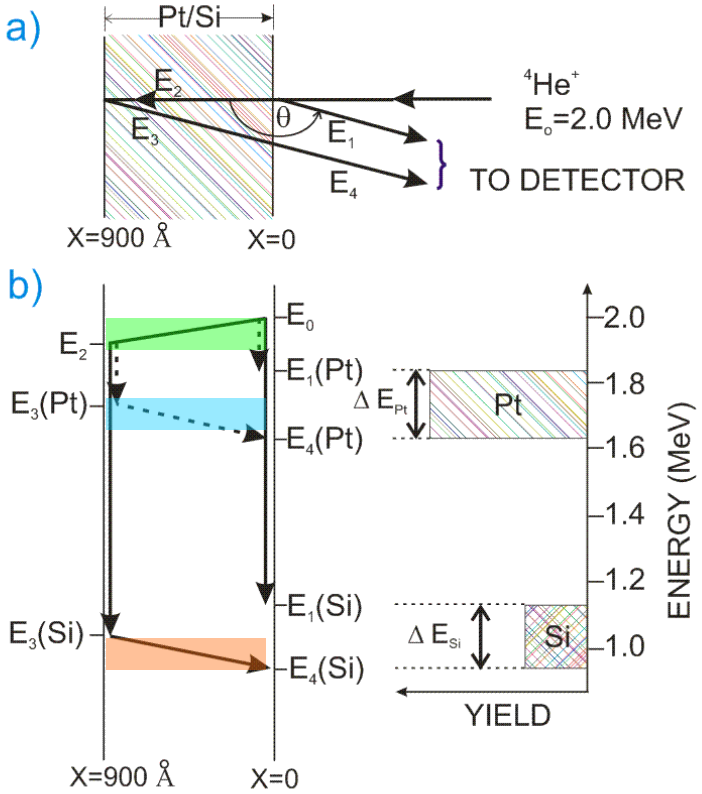


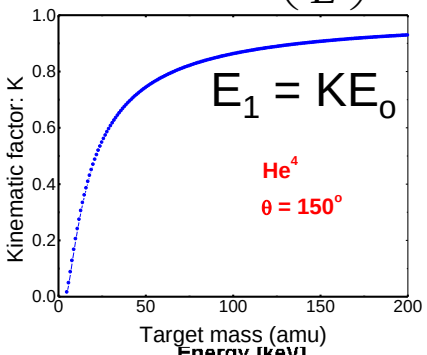
Figure after W.-K. Chu, J. W. Mayer, and M.-A. Nicolet, *Backscattering Spectrometry* (Academic Press, New York, 1978).

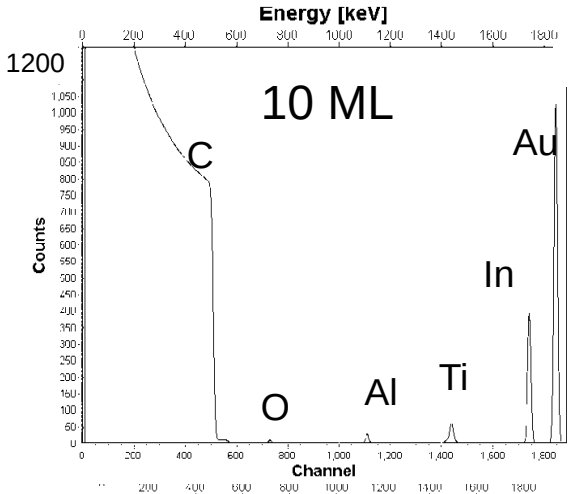
RBS – Simulated Spectra

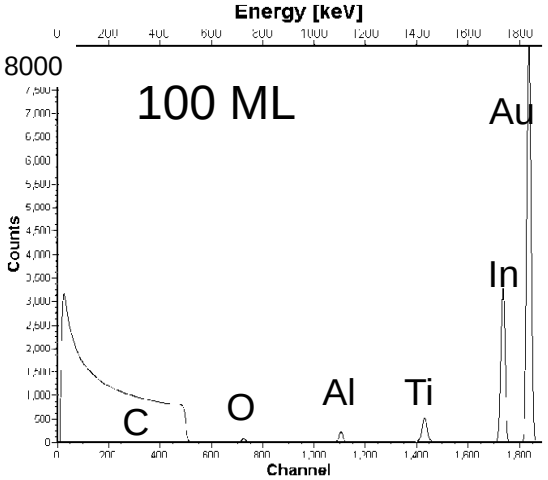
hypothetical alloy $Au_{0.2}In_{0.2}Ti_{0.2}Al_{0.2}O_{0.2}/C$

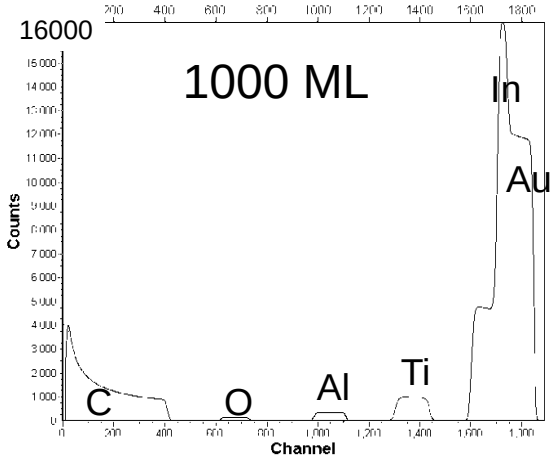
Element (Z,M): O(8,16), Al(13,27), Ti(22,48), In(49,115), Au(79,197)

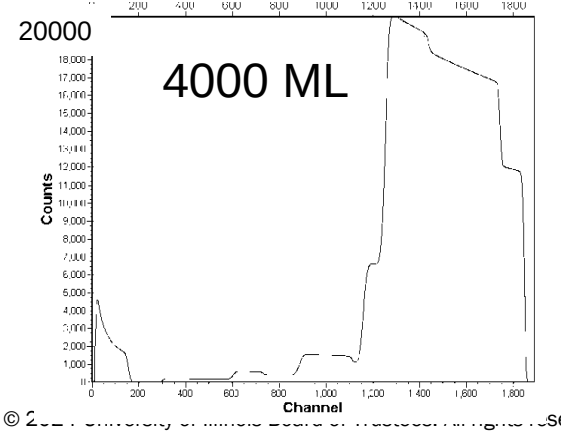
$$\sigma_R(E,\theta) \propto \left(\frac{Z_2}{E}\right)^2$$

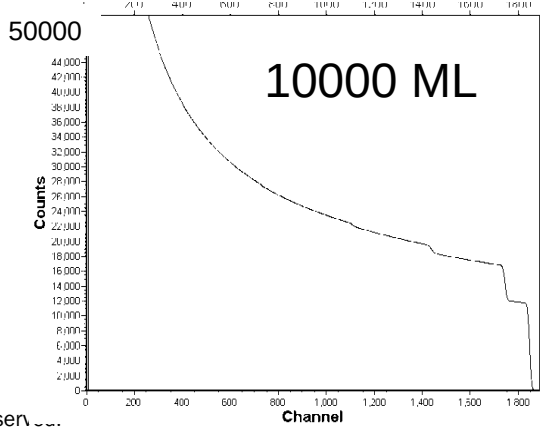




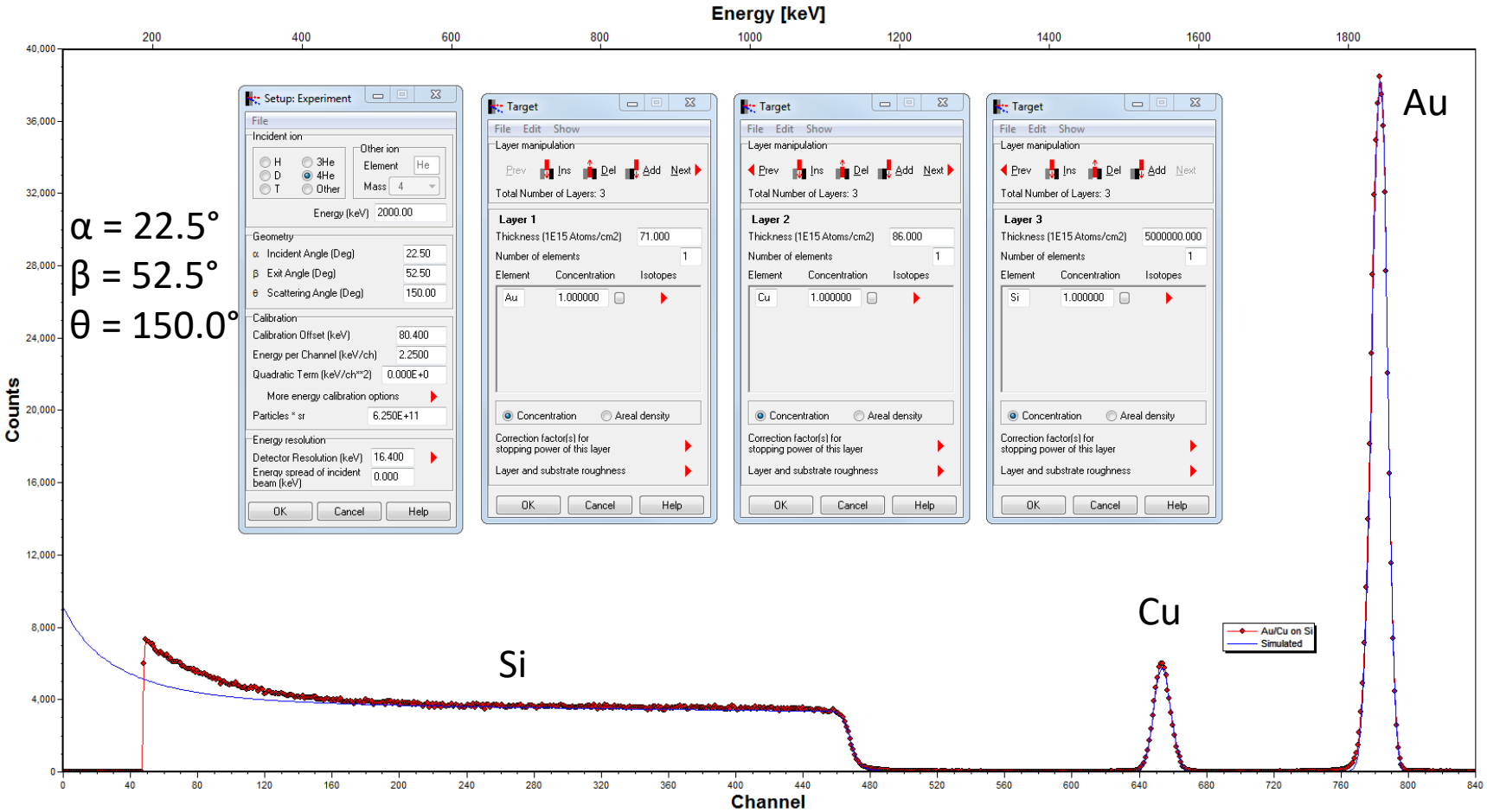




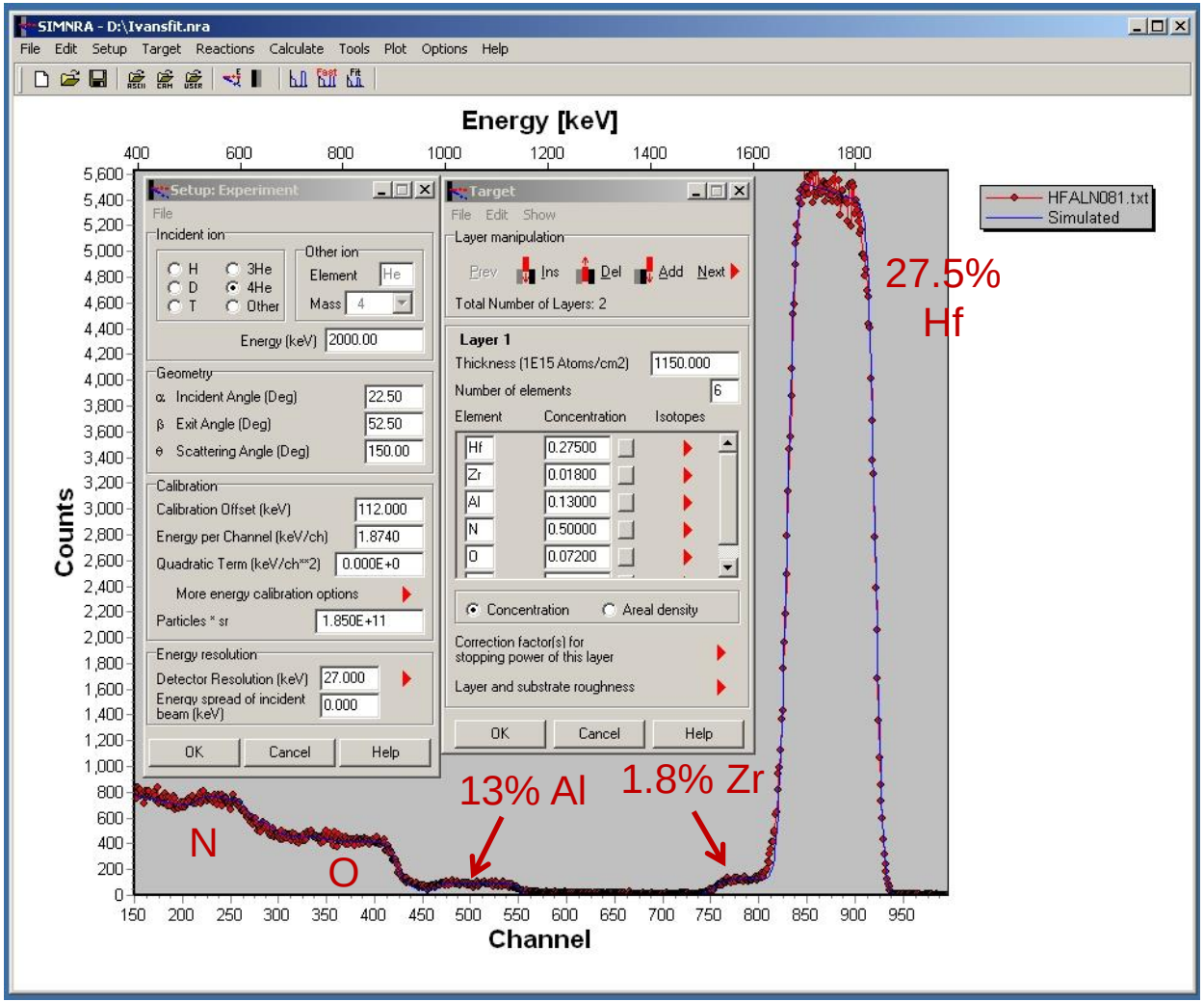




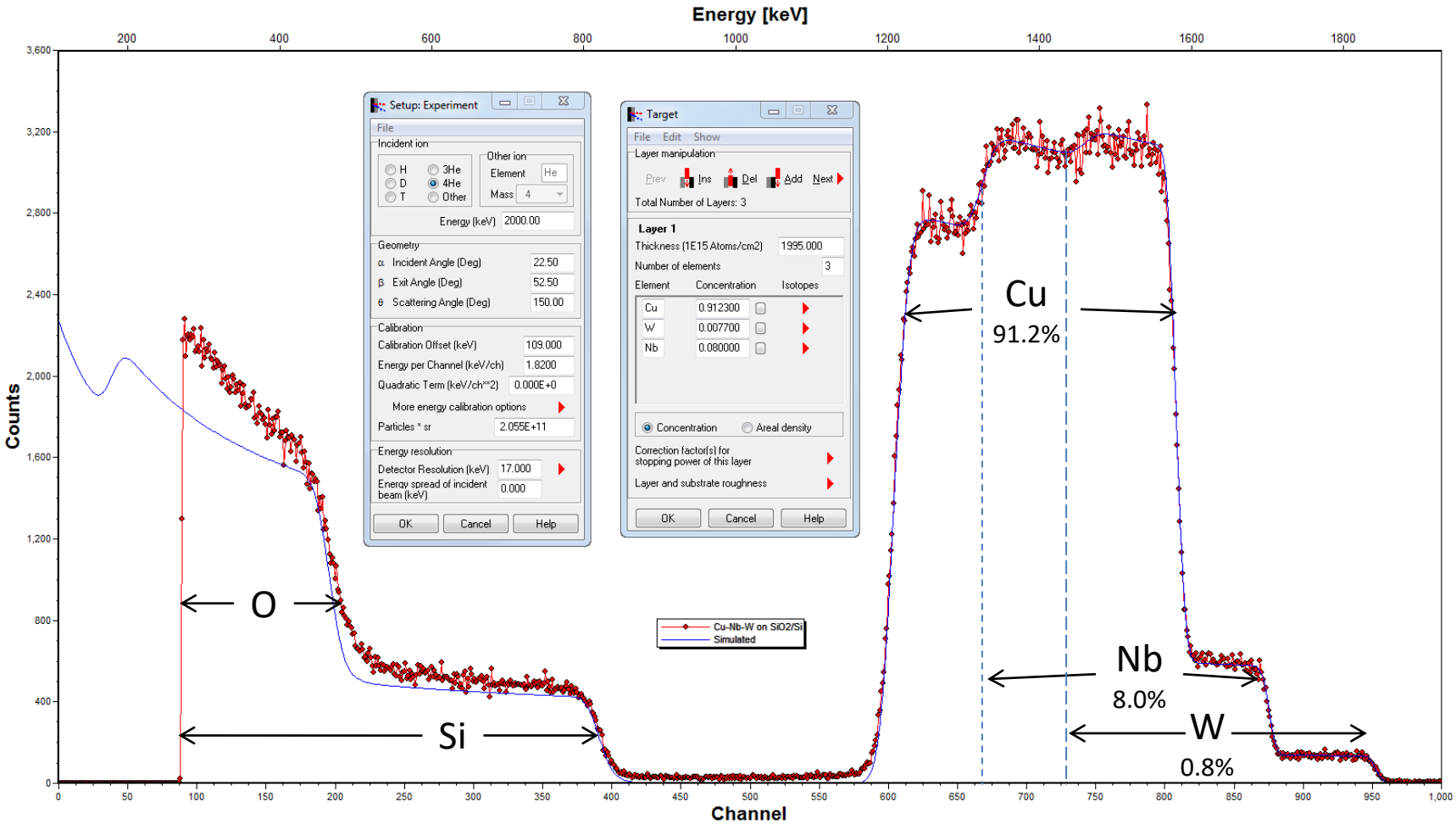
Calibration Sample



SIMNRA Simulation Program for RBS and ERD



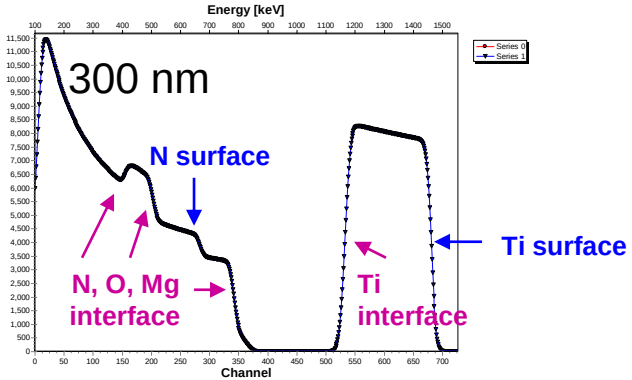
Cu-Nb-W Alloy on SiO_2/Si

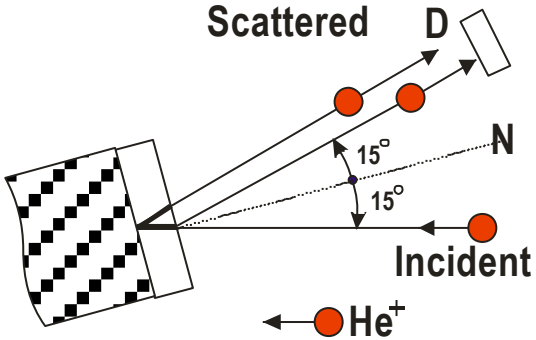


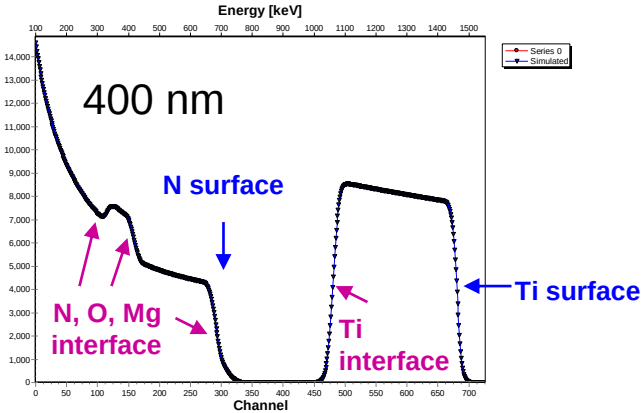
Courtesy N. Vo and R.S. Averback

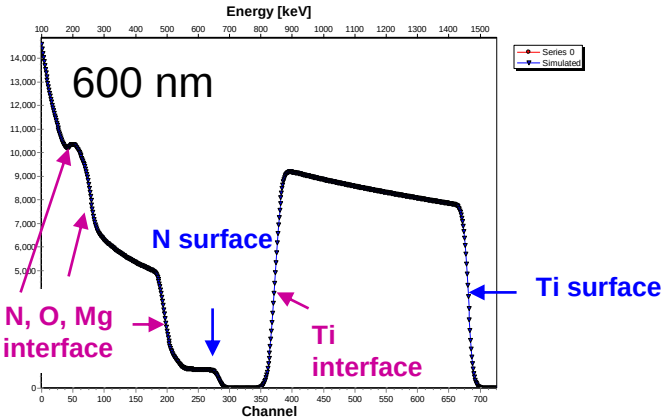
Thickness Effects

TiN/MgO



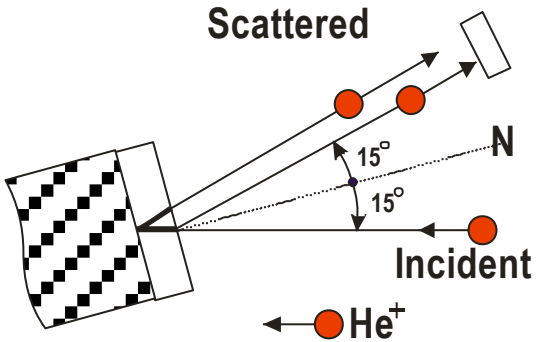


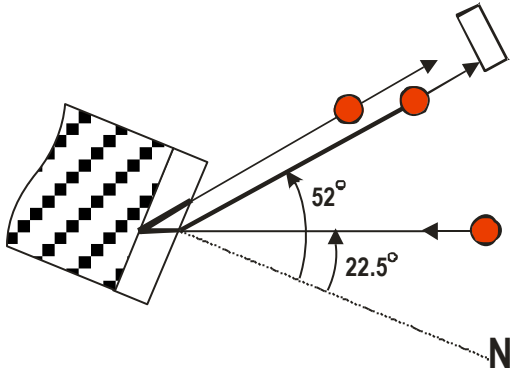


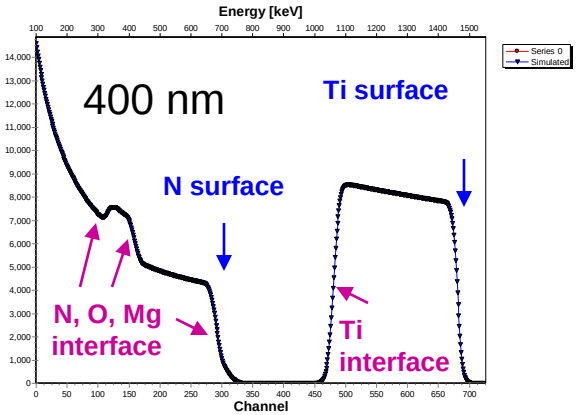


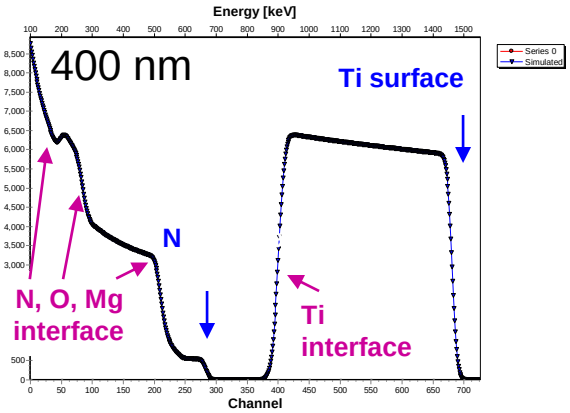
Incident Angle Effects

TiN/MgO



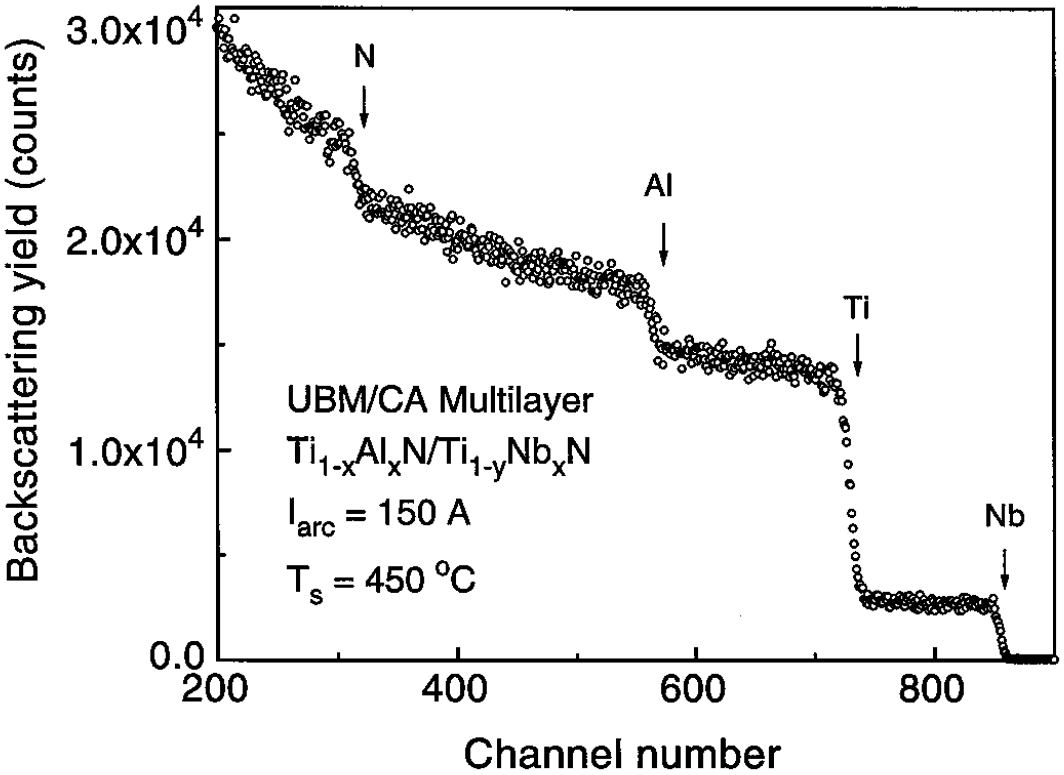






Surface peaks do not change position with incident angle

Example: Average Composition

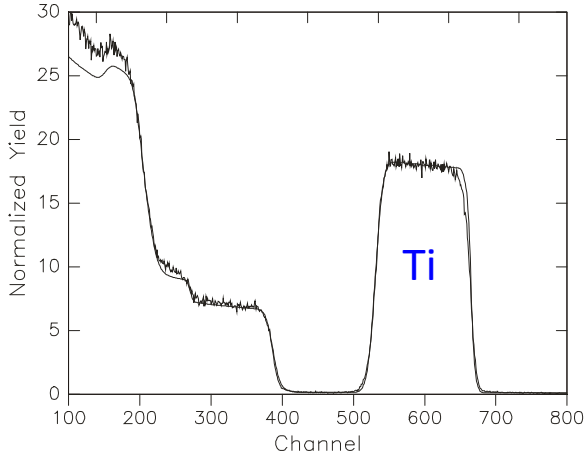


I. Petrov, P. Losbichler, J. E. Greene, W.-D. Münz, T. Hurkmans, and T. Trinh, *Thin Solid Films,* 302 179 (1997)

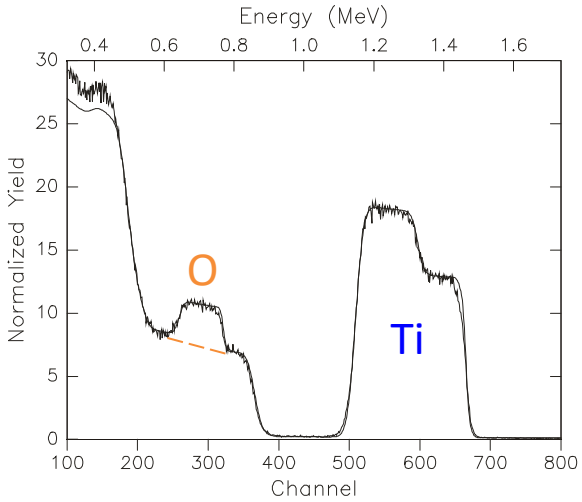
RBS: Oxidation Behavior

TiN/SiO_2

As-deposited



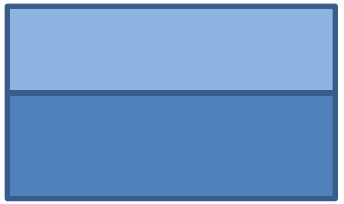
Annealed in atmosphere for 12 min at T_a = 600 °C

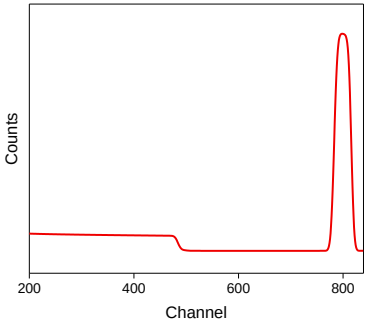


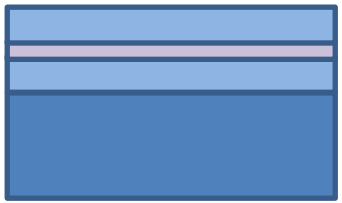
Experimental spectra and simulated spectra by RUMP

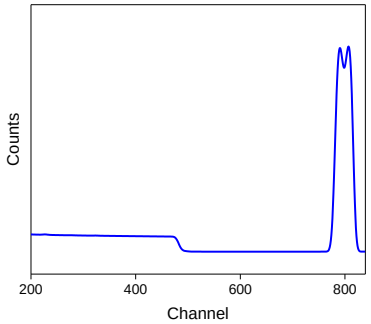
Areal mass density by RBS

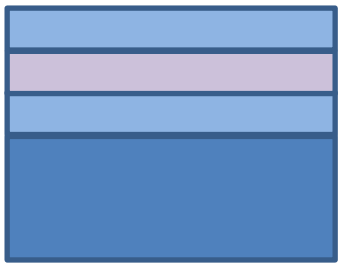
- Free-standing polyamide films are too thin to give sufficient signal in the RBS.
- Use the added stopping power of the polymer to split the Pt peak in the RBS spectrum.

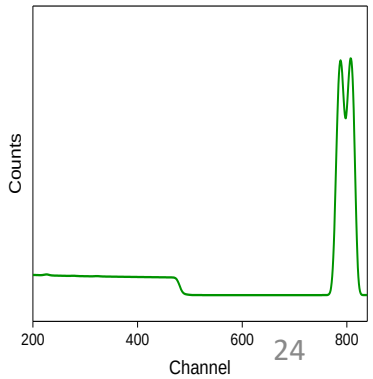






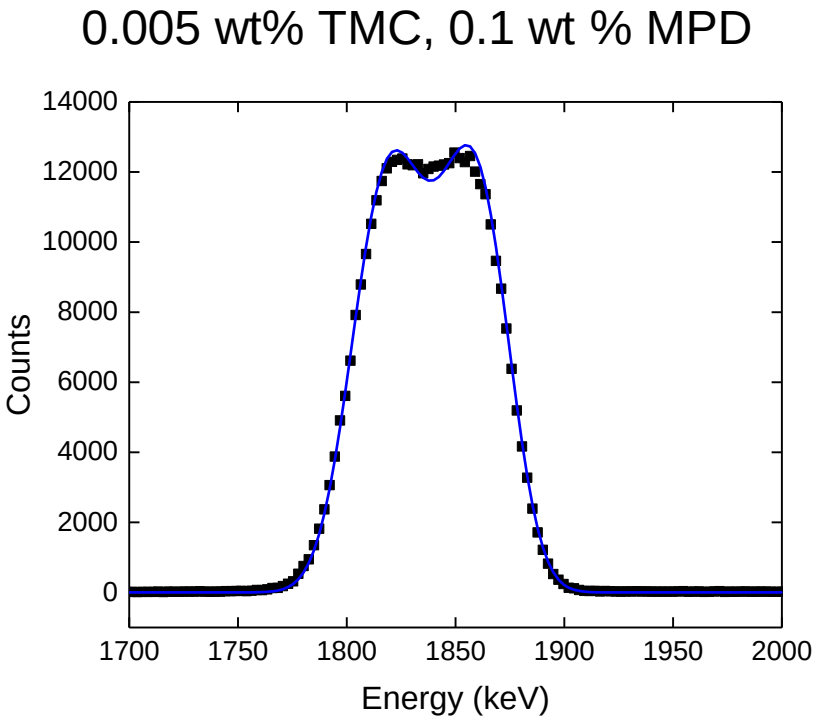


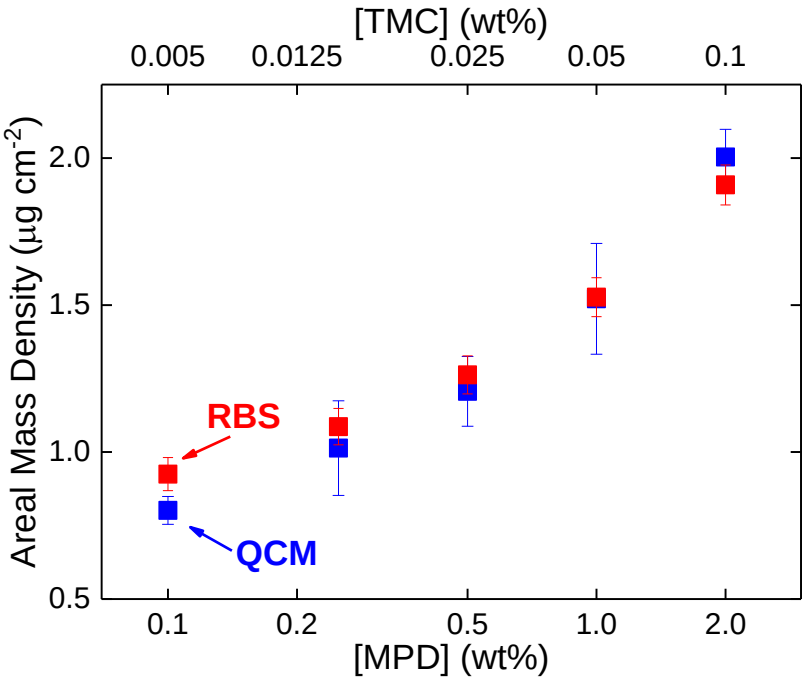




JM Dennison, X Xie, CJ Murphy, DG Cahill - ACS Applied Nano Materials, 2018

Areal mass density by RBS





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Additional Analytical Capabilities

Elastic Recoil Detection

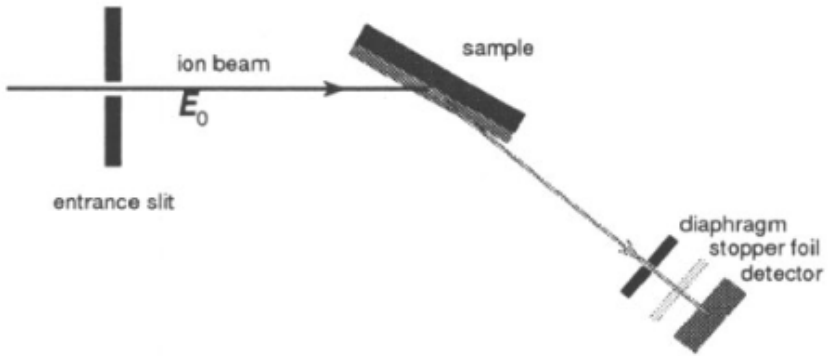
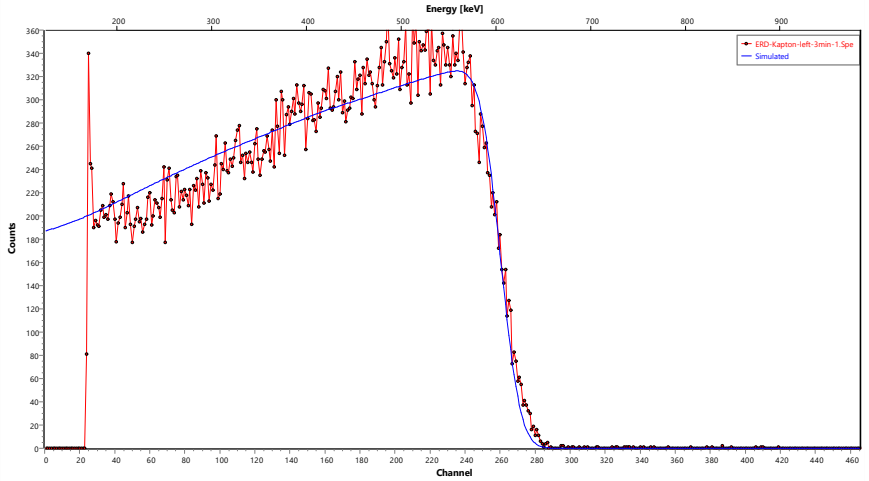


Figure 3. Schematic view of ERD in the conventional set-up.

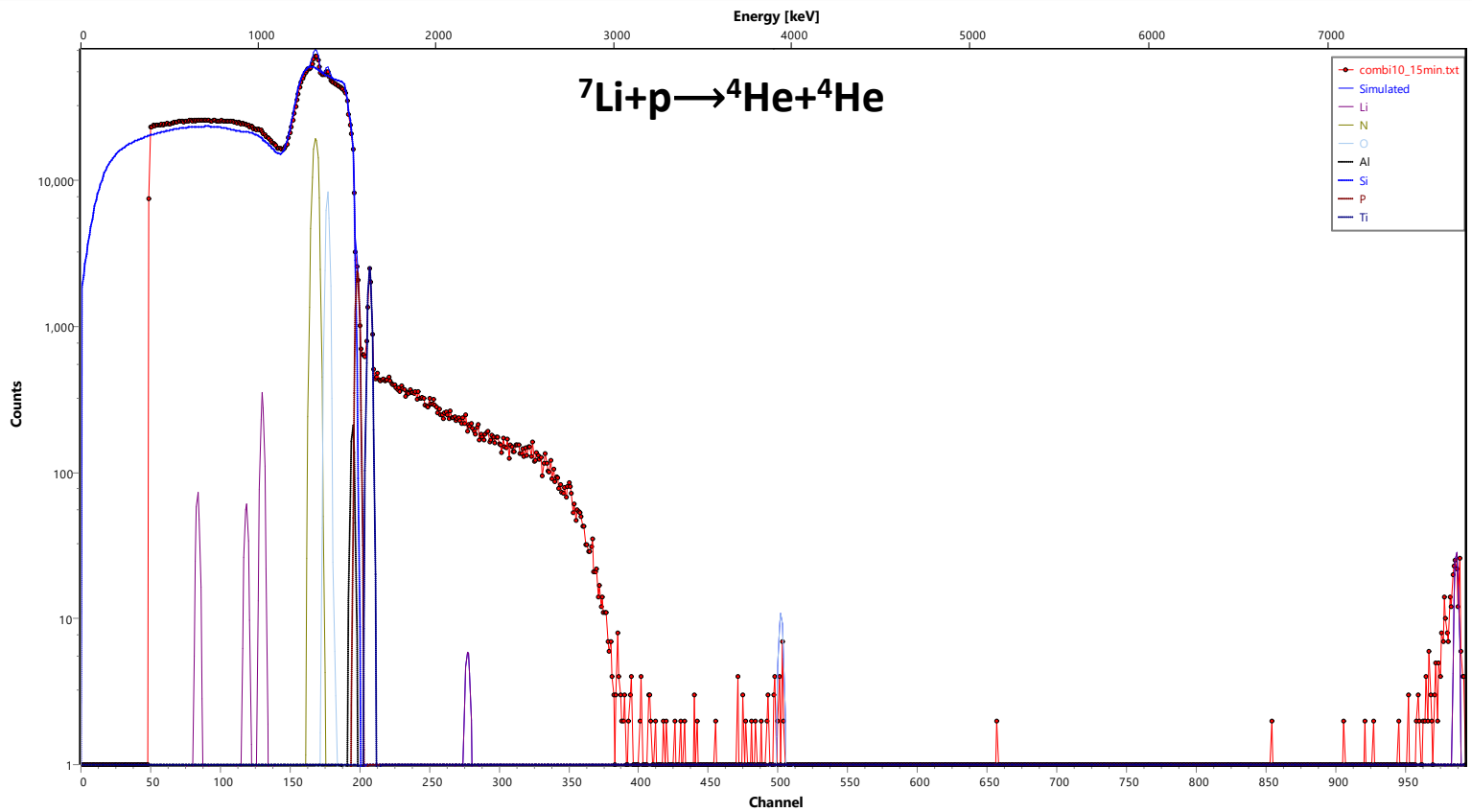
W M Arnold Bik and F H P M Habraken 1993
Rep. Prog. Phys. 56 859



Kapton
Courtesy of X. Ji, D.G. Cahill
University of Illinois

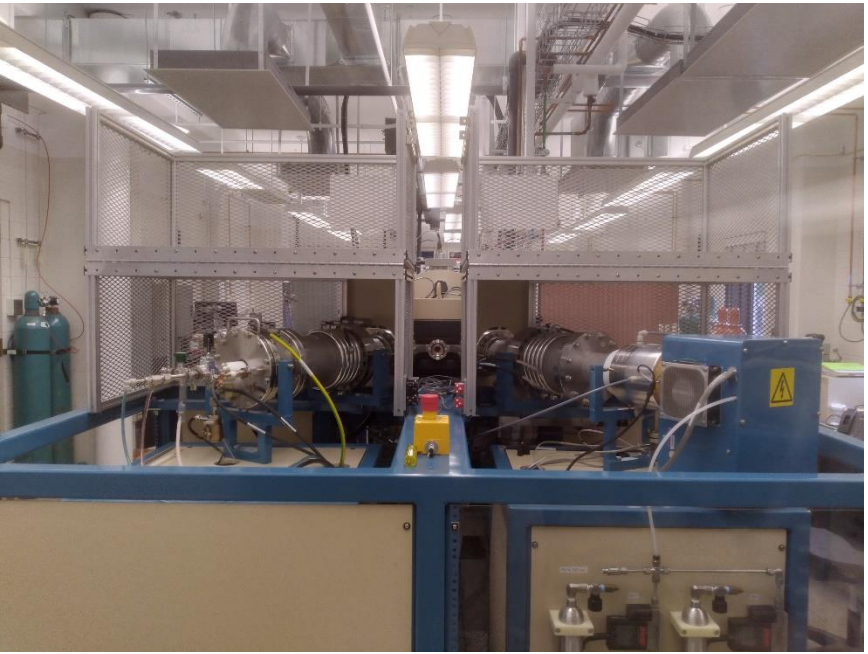
Additional Analytical Capabilities

Nuclear Reaction Analysis



Courtesy of E.J. Cho, N. Perry, University of Illinois

Ion Irradiation

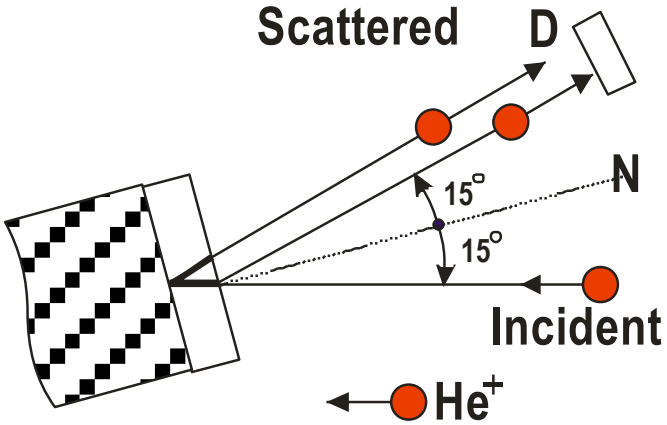


SNICS source

He source

Irradiation end station

RBS Summary



- Quantitative technique for elemental composition
- Requires flat samples; beam size Φ1-3 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 μm

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