Rutherford Backscattering Spectrometry

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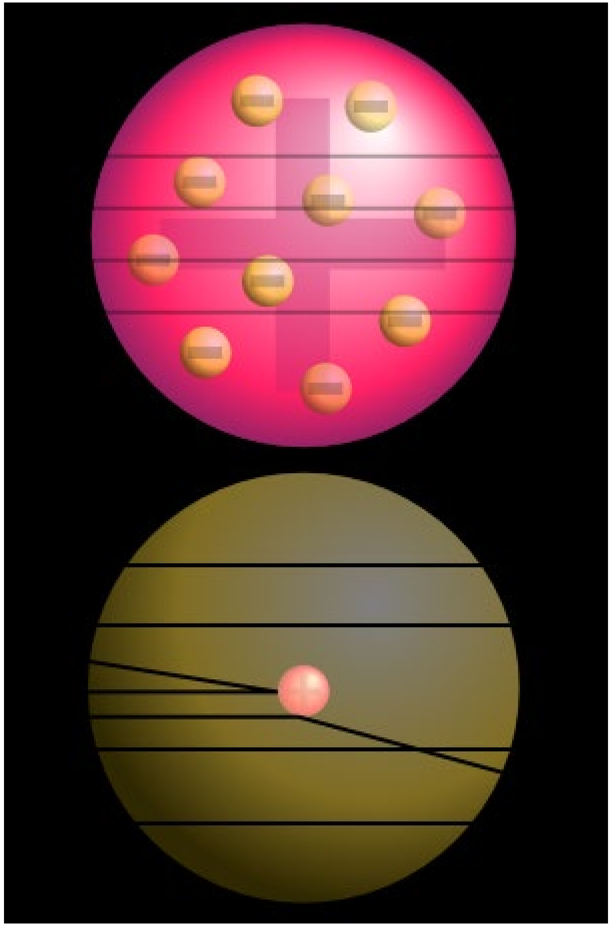
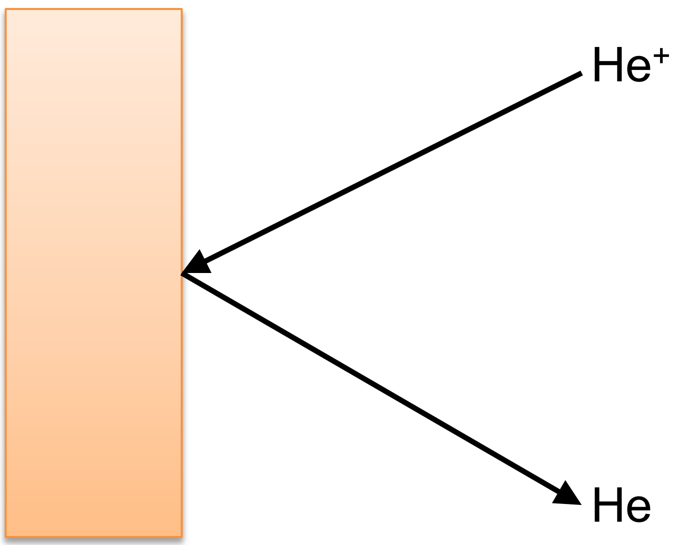
Geiger-Marsden Experiment



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

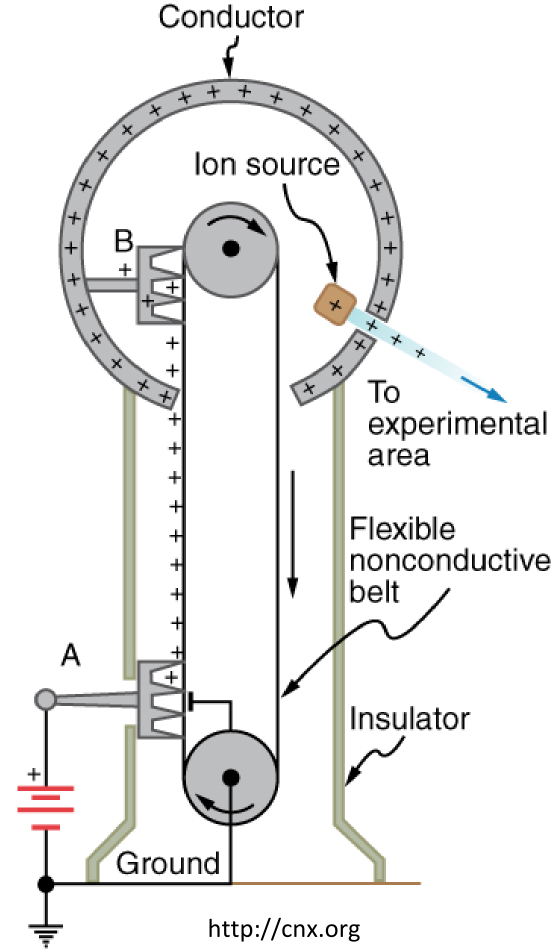
Bottom: Observed results:
a small portion of the particles were deflected, indicating a small, concentrated positive charge.



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

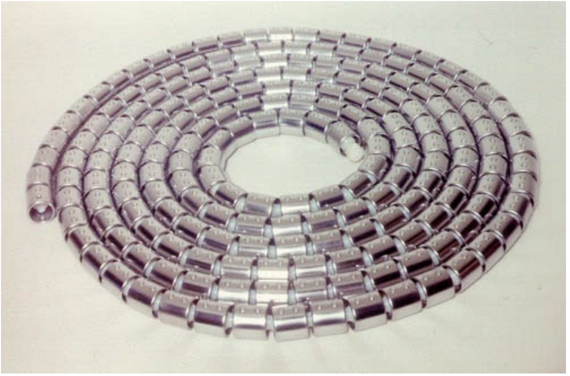
http://archive.thedailystar.net/newDesign/print_news.php?nid=73473



http://cnx.org

3 MeV Pelletron accelerator

beam size Φ1-3 mm
flat sample
can be rotated



Pelletron system consists of

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

NEC Pelletron

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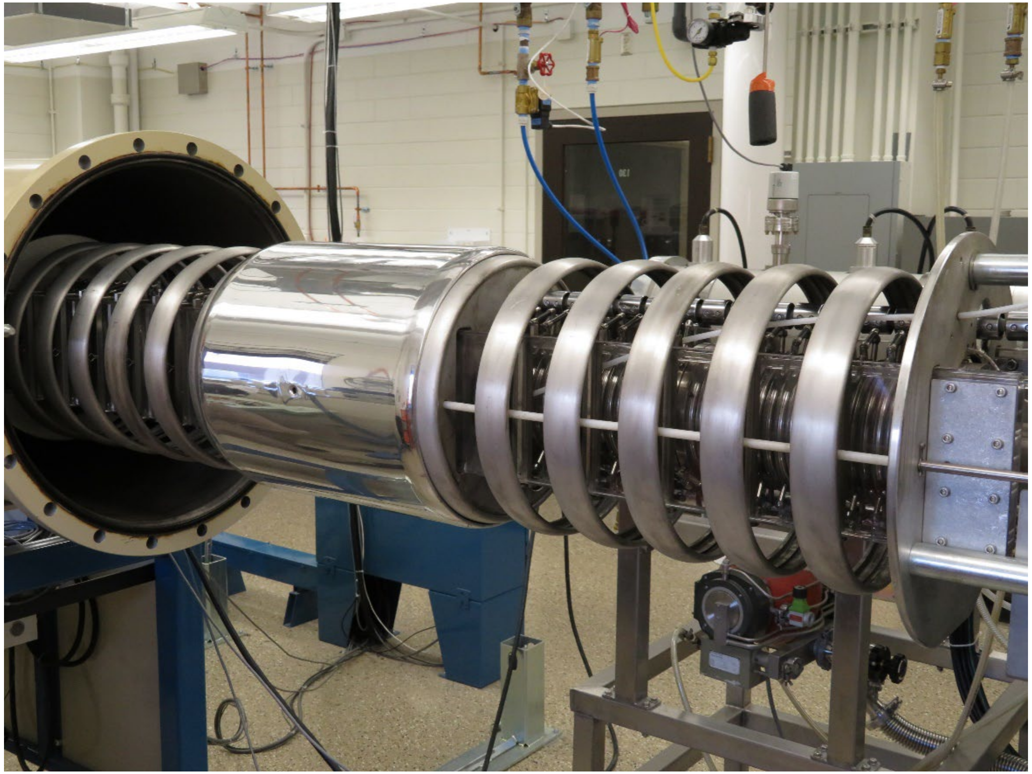

NEC Pelletron

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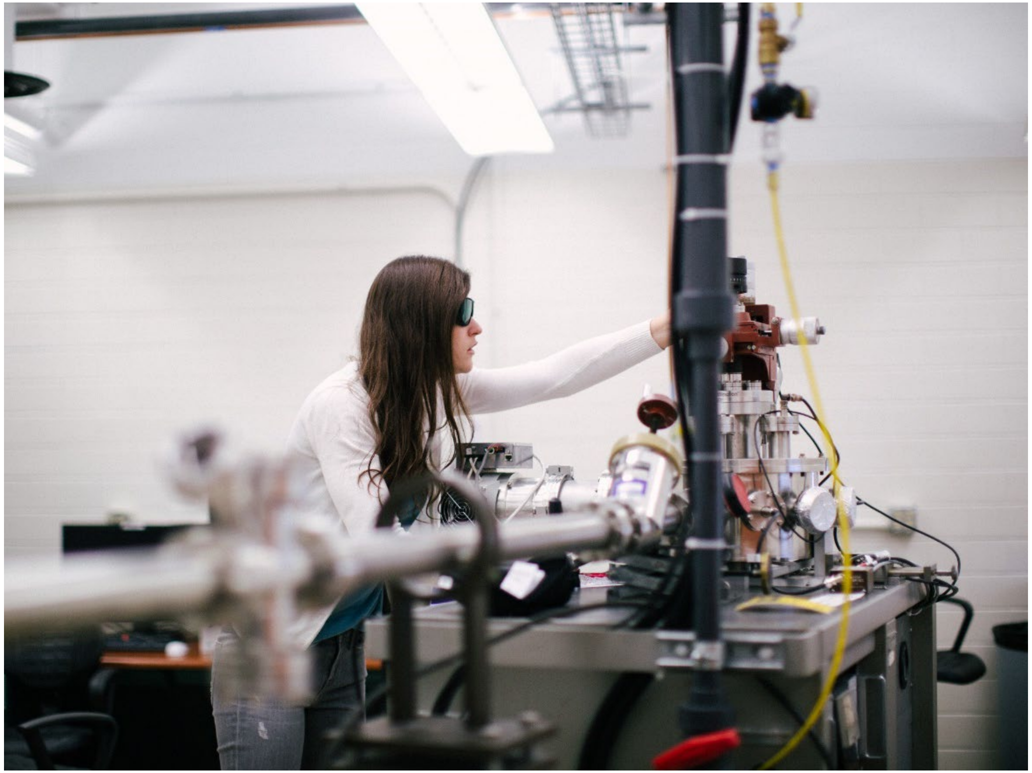
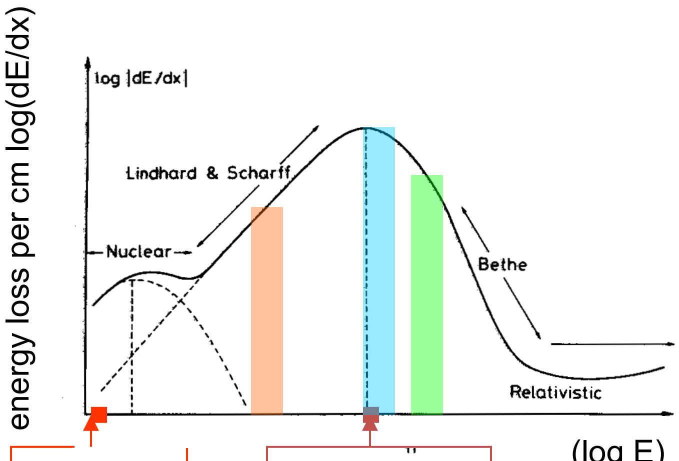
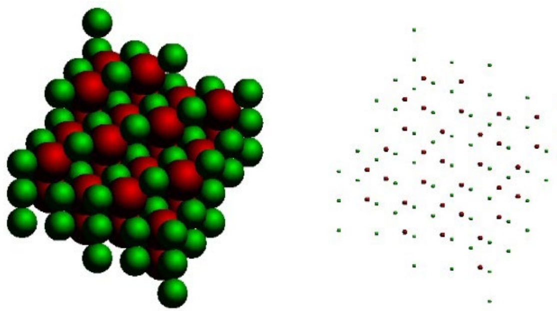


Primary Beam Energy



1 keV   1 MeV



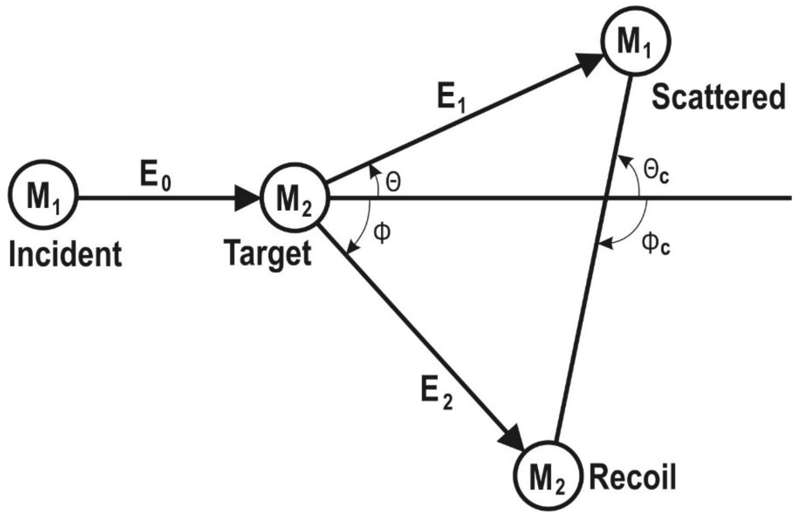
1 keV   1 MeV

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 Two-Body Collision



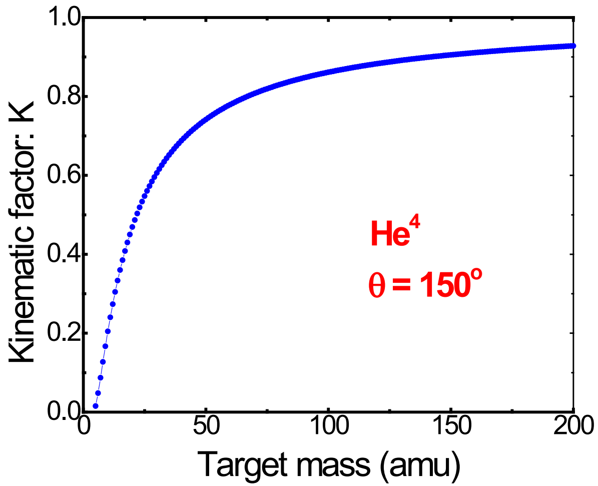
Elastic Scattering

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

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

$$E_1 = KE_o$$

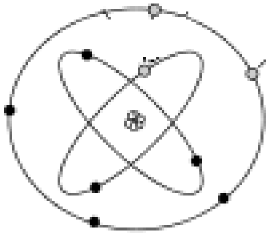
$$K = \left(\frac{\sqrt{M_t^2 - M_i^2 \sin^2\theta} + M_i \cos\theta}{M_i + M_t} \right)^2$$

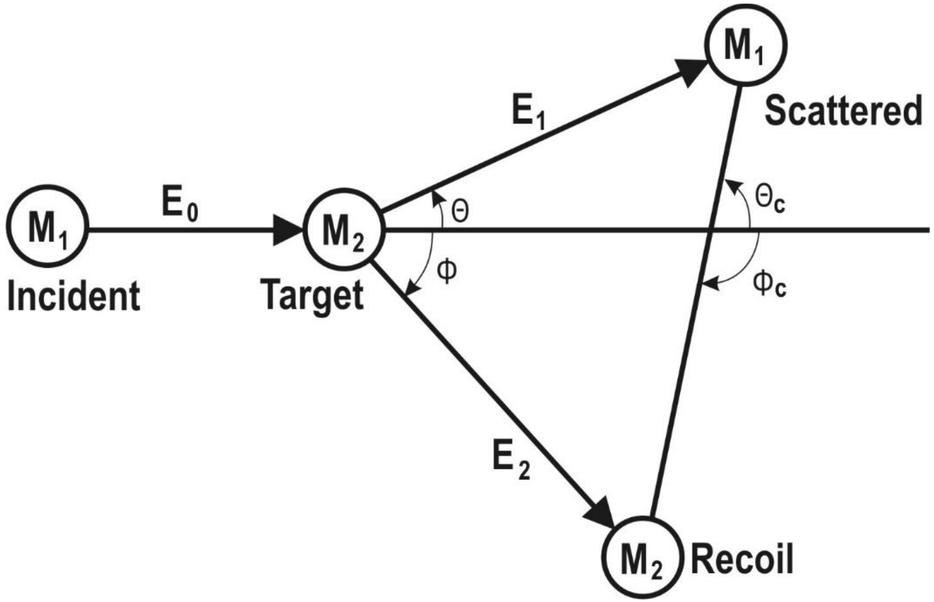


$M_1 < M_2$, $0 \leq \theta \leq 180^o$

$0 \leq \Phi \leq 90^o$

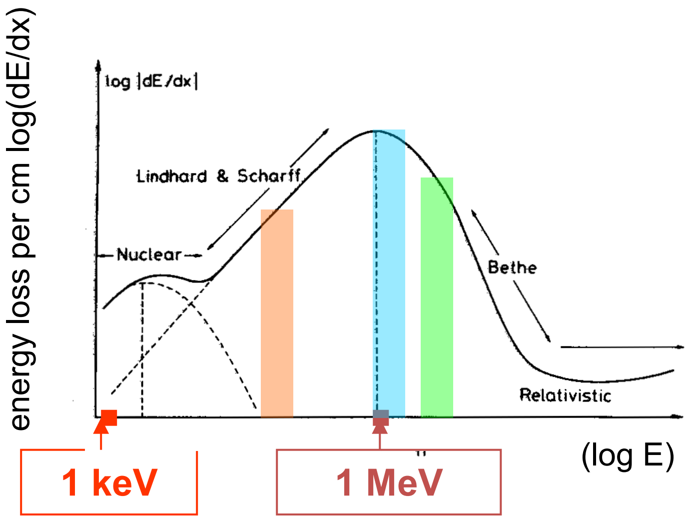
RBS: He backscatters from $M_2 > 4$





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

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



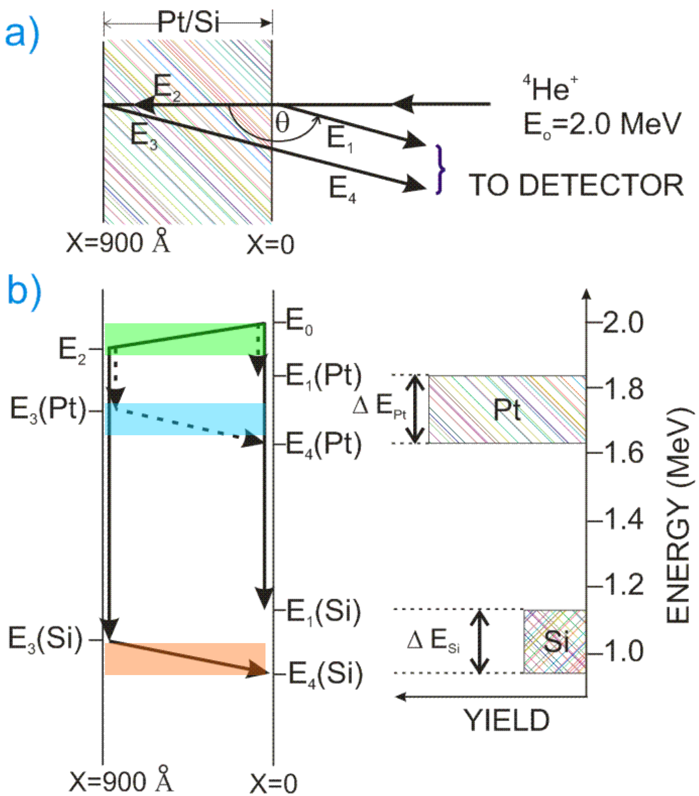
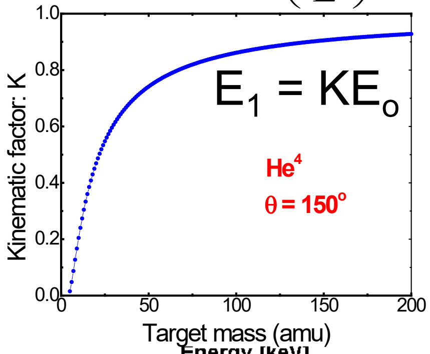


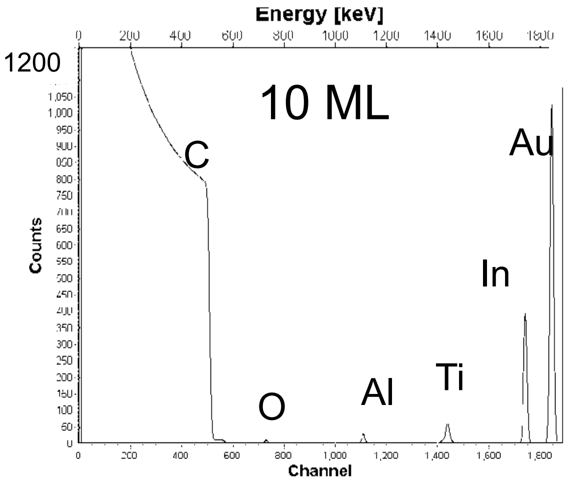
Figure after W.-K. Chu, J. W. Mayer, and M.-A. Nicolet, *Backscattering Spectrometry* (Academic Press, New York, 1978).

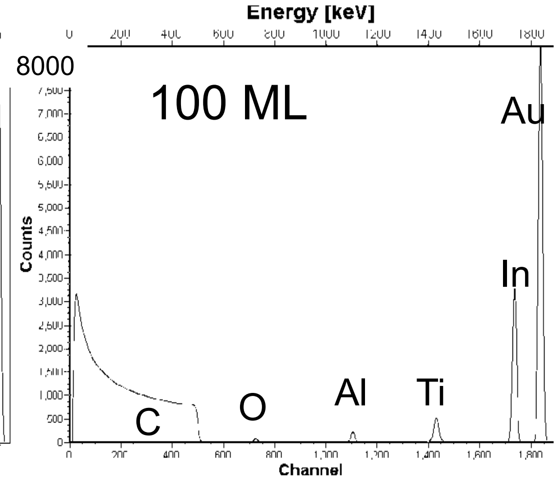
hypothetical alloy $Au_{0.2}In_{0.2}Ti_{0.2}Al_{0.2}O_{0.2}/C$

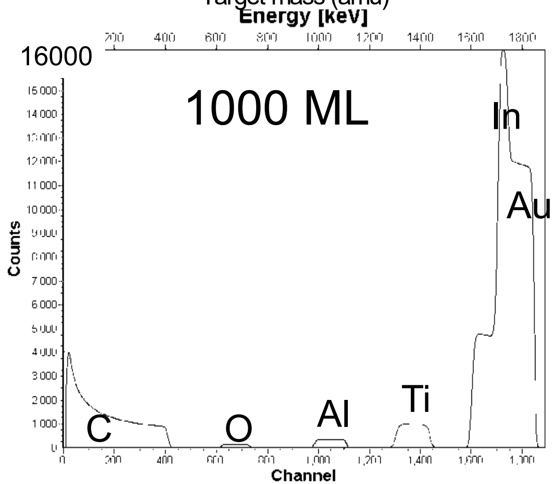
Element (Z,M): O(8,16), Al(13,27), Ti(22,48), In(49,115), Au(79,197)

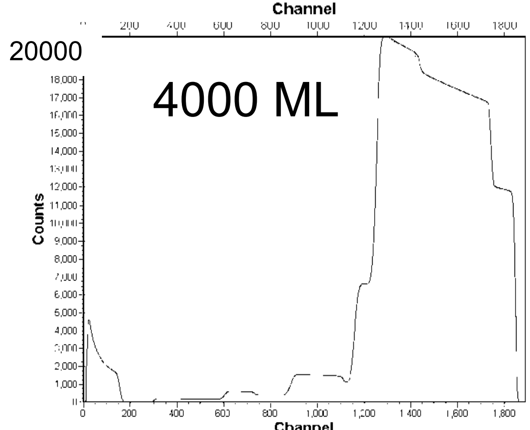
$$\sigma_R(E,\theta) \propto \left(\frac{Z_2}{E}\right)^2$$

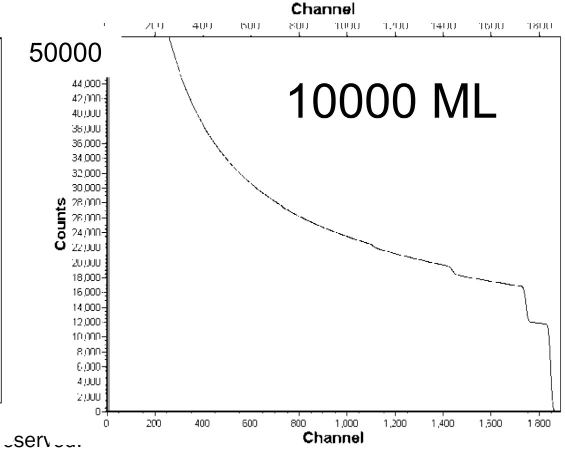




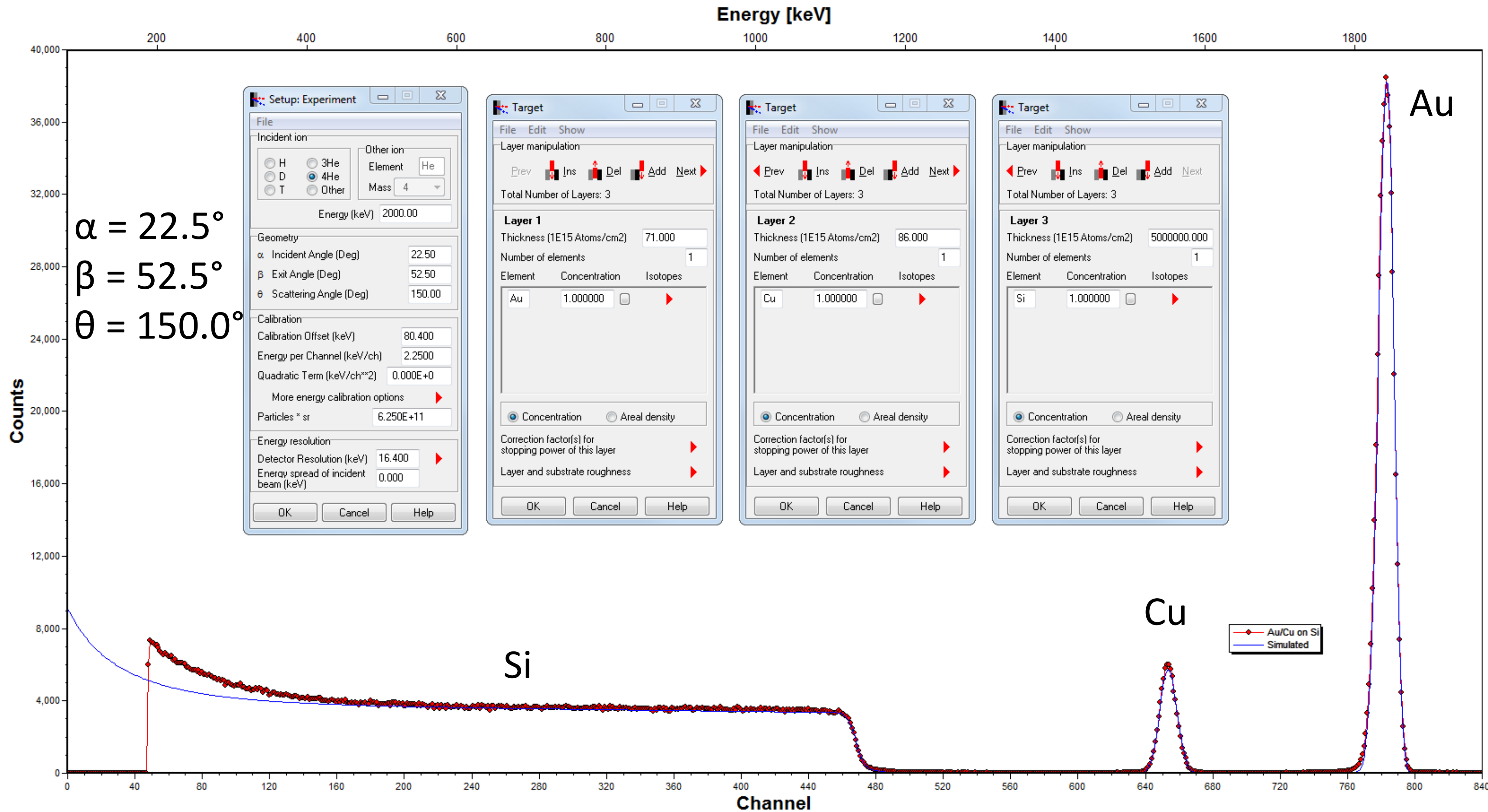




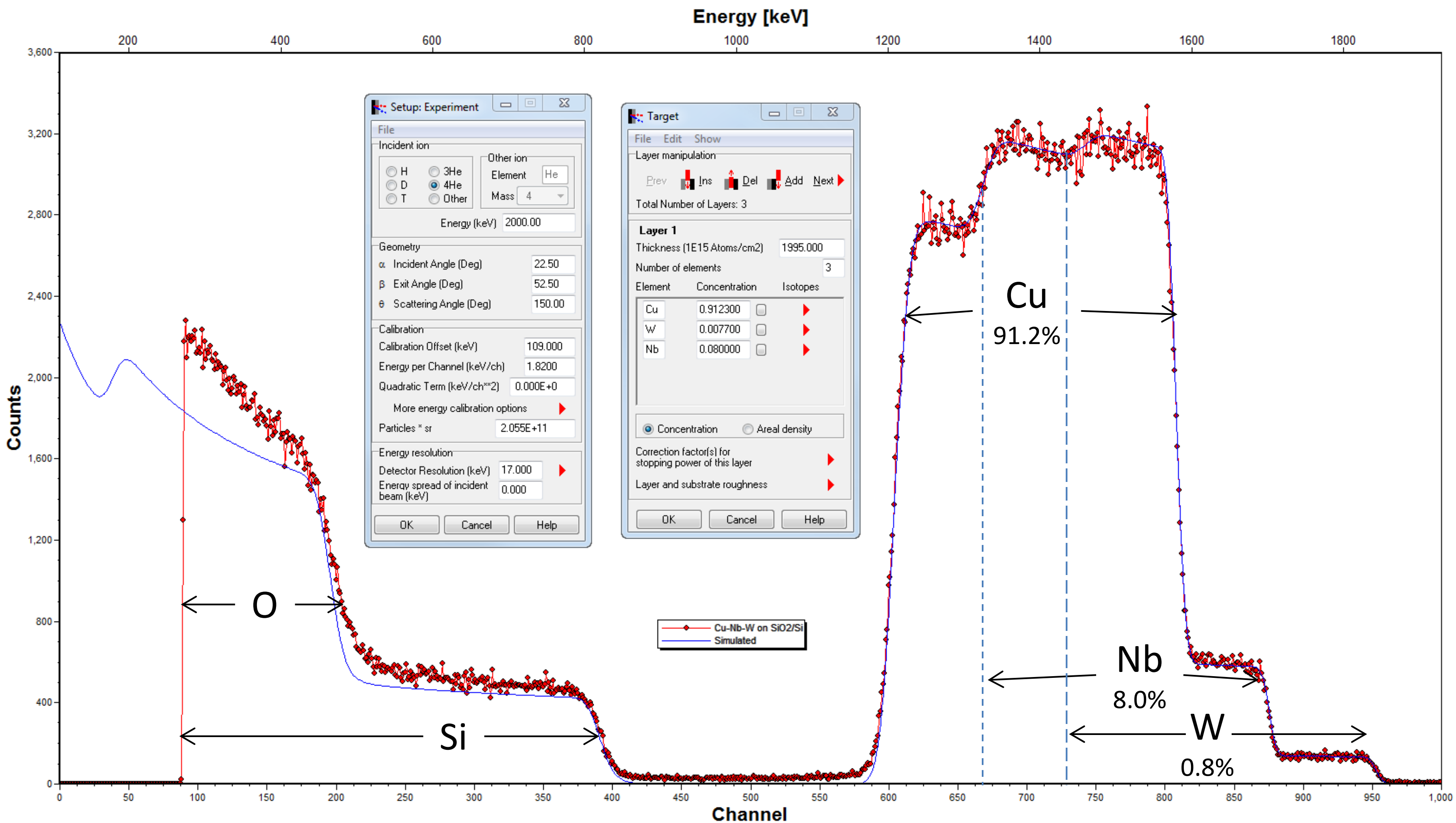




Calibration Sample

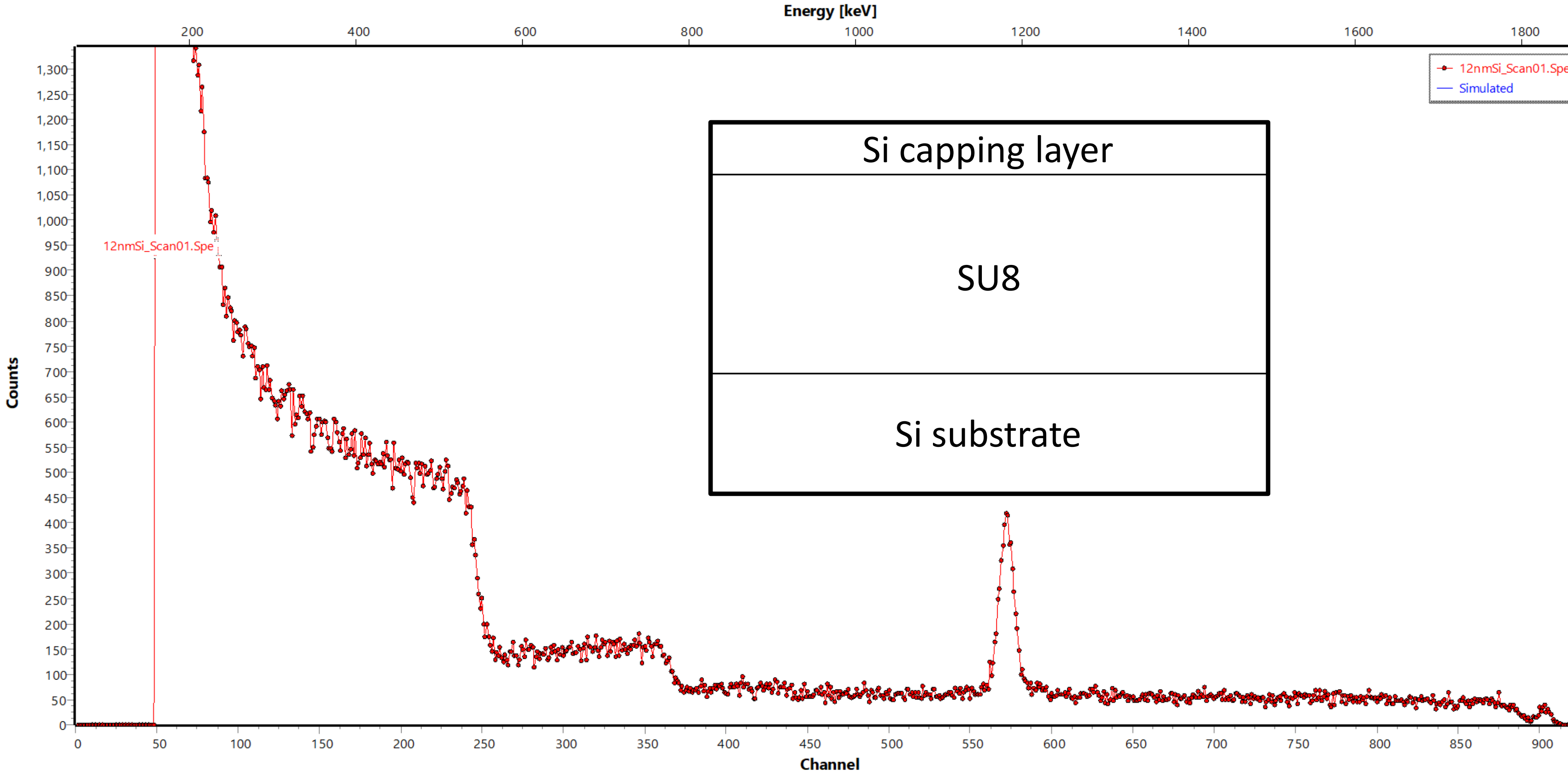


Cu-Nb-W Alloy on SiO_2/Si



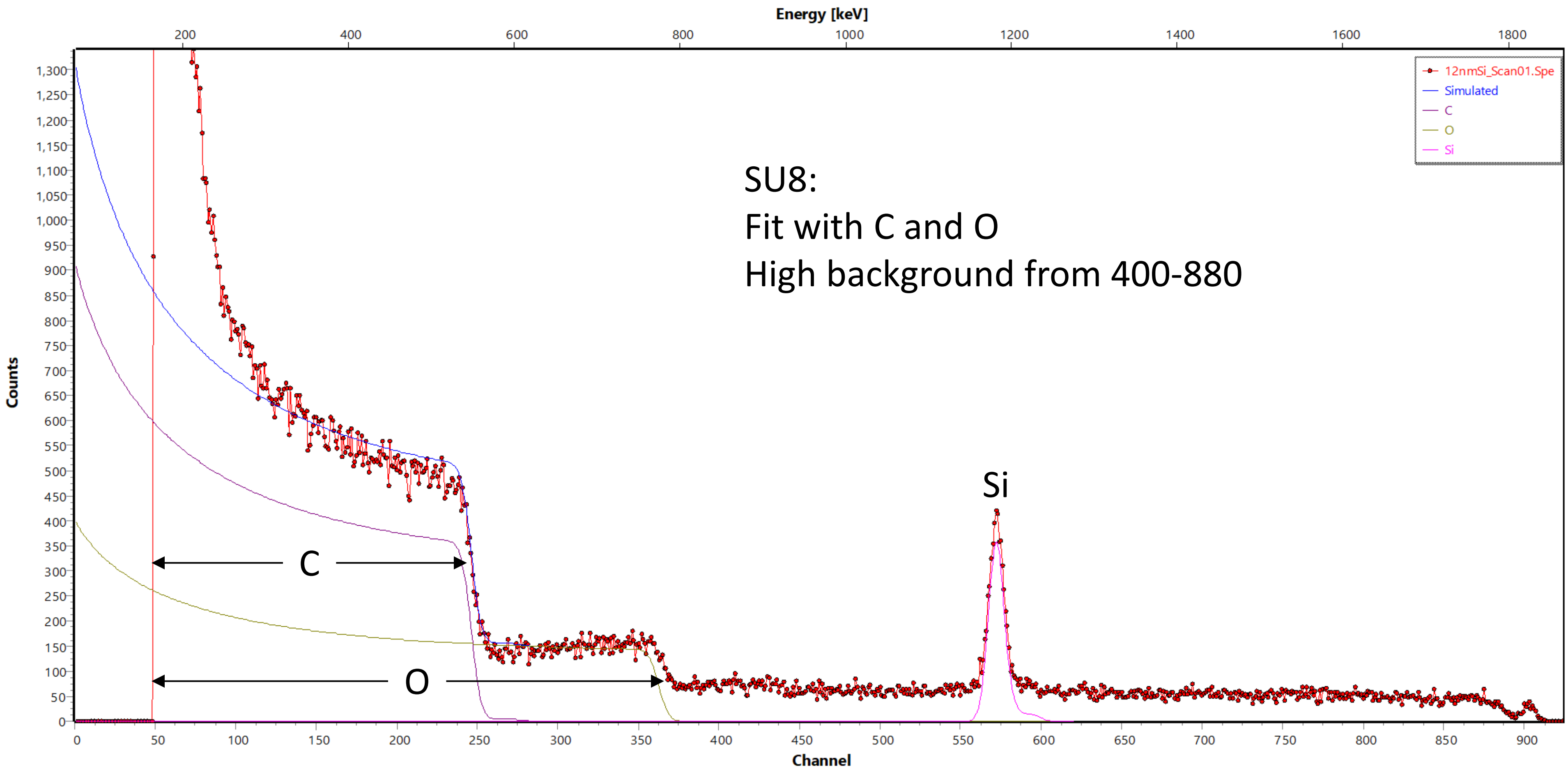
Courtesy N. Vo and R.S. Averback

Si/SU-8/Si



Courtesy J. Sun and D.G. Cahill

Si/SU-8/Si



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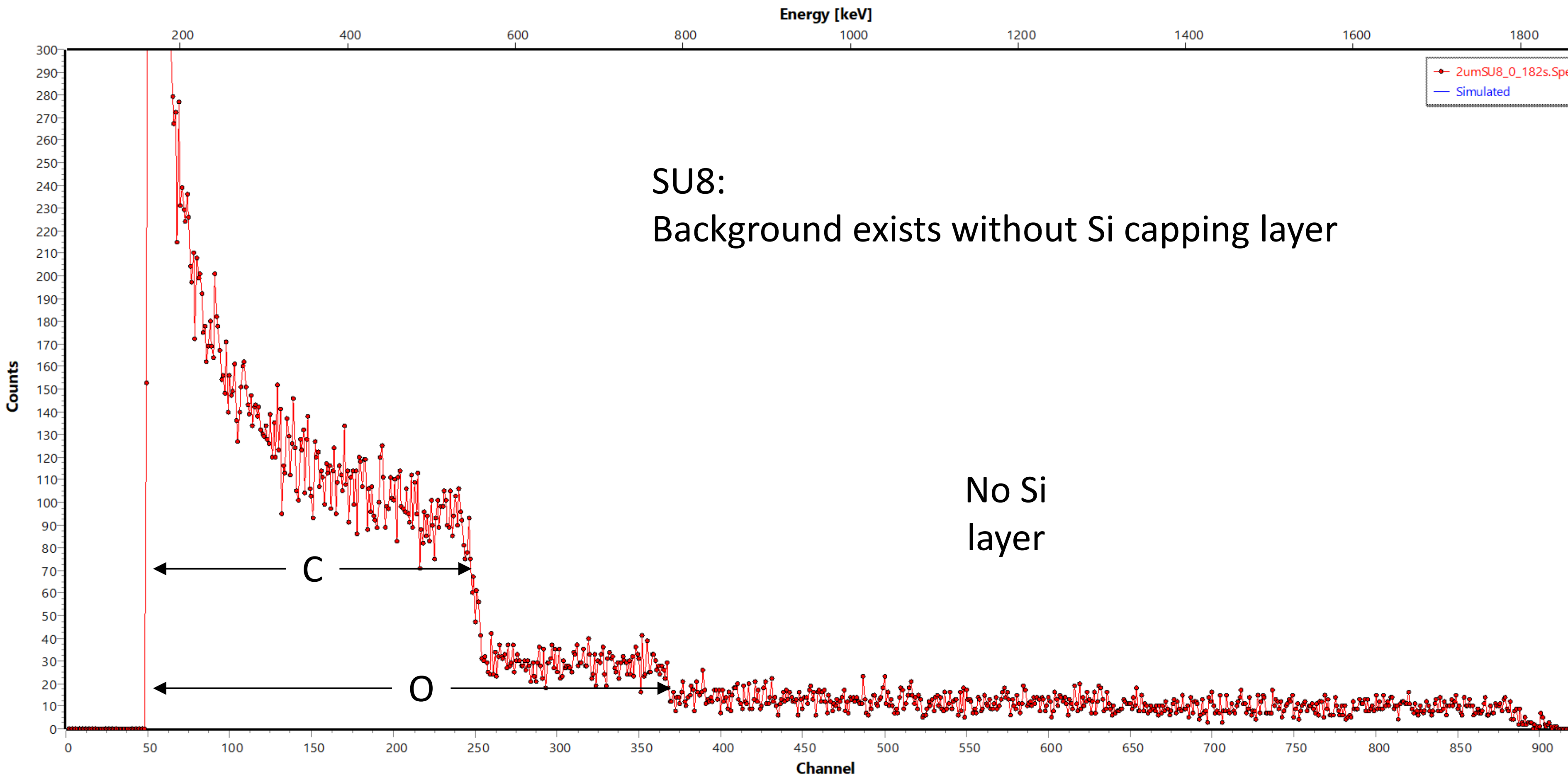
Si/SU-8/Si



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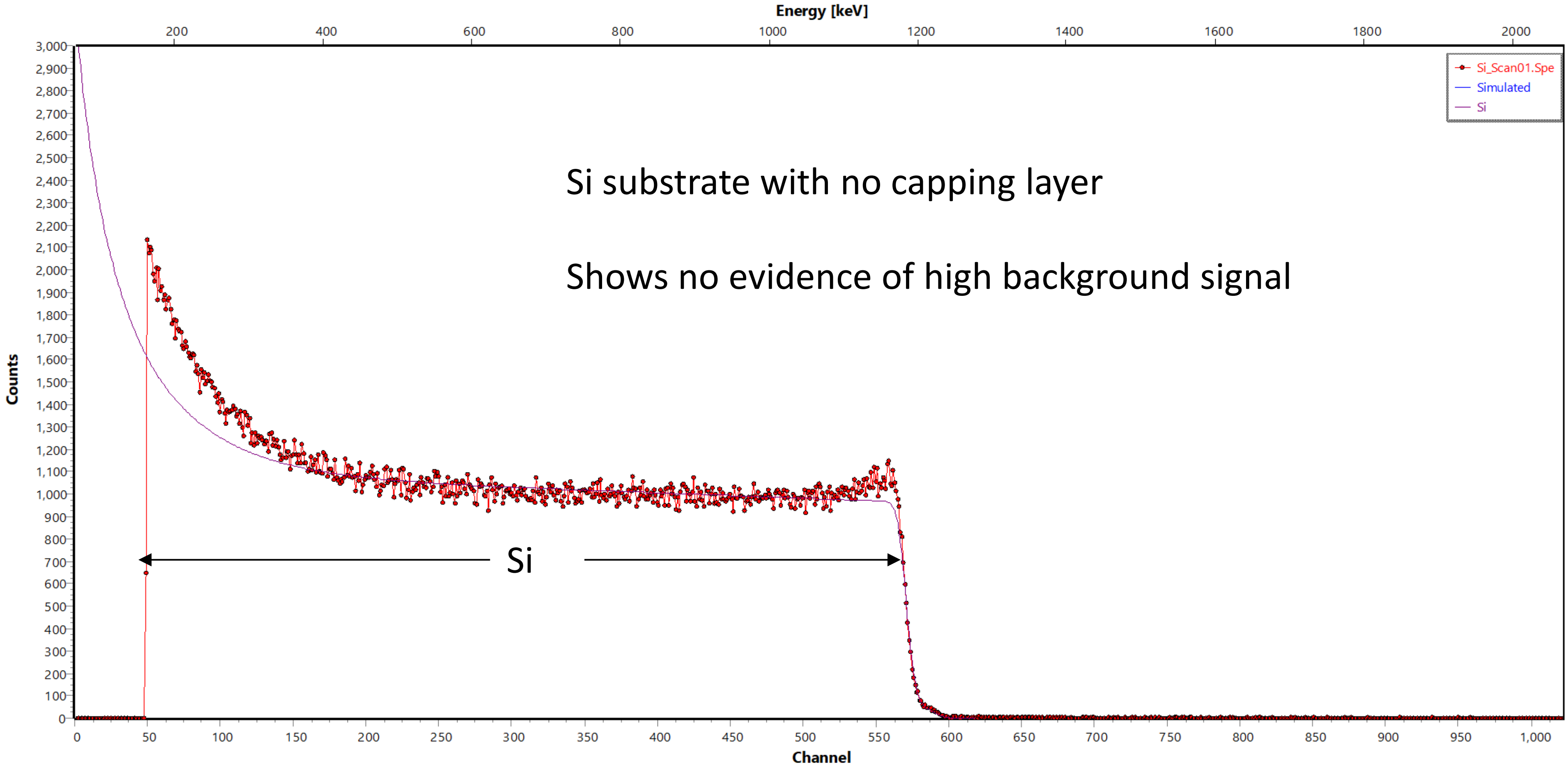

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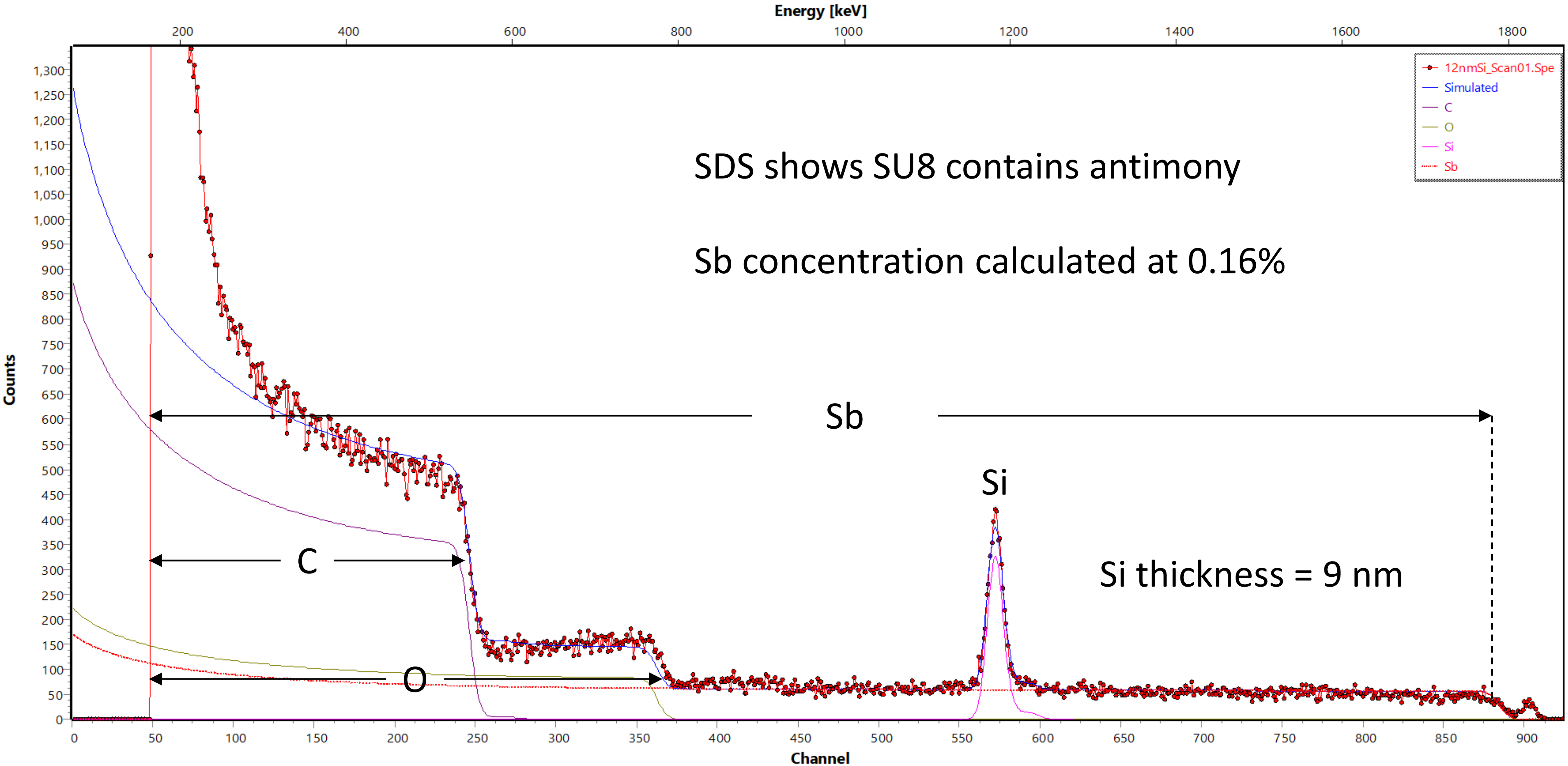
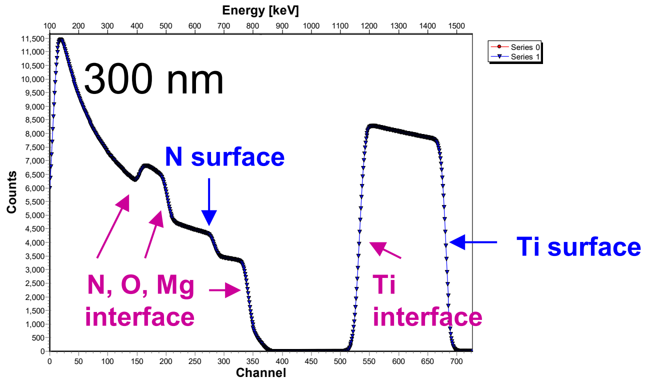
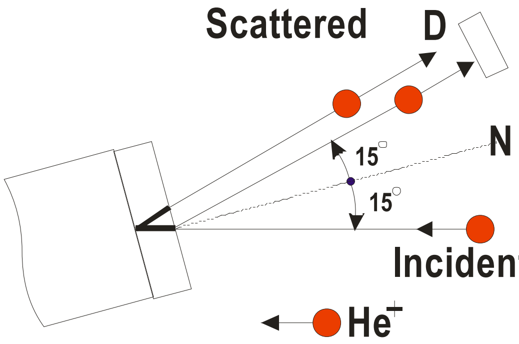
Si/SU-8/Si

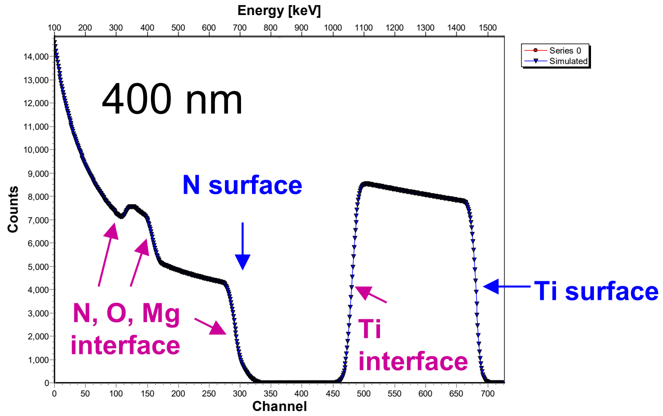


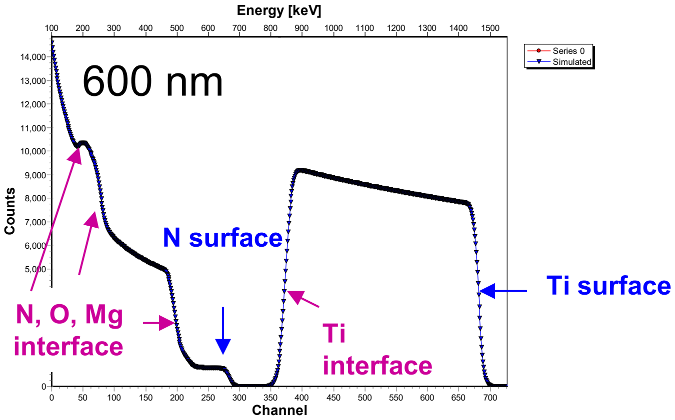
Courtesy J. Sun and D.G. Cahill

TiN/MgO

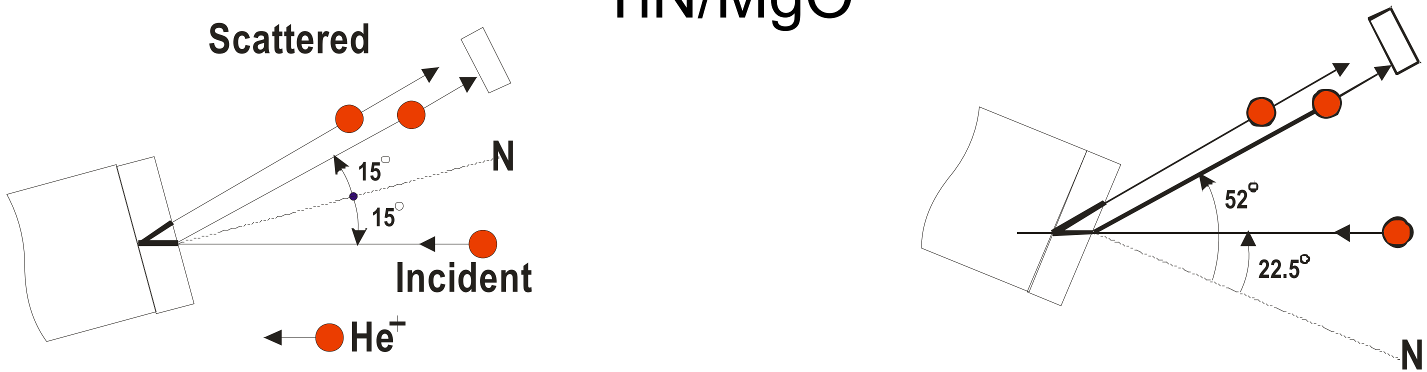

300 nm
N surface
N, O, Mg
interface
Ti
interface
Ti surface
Energy [keV]
Counts
Channel

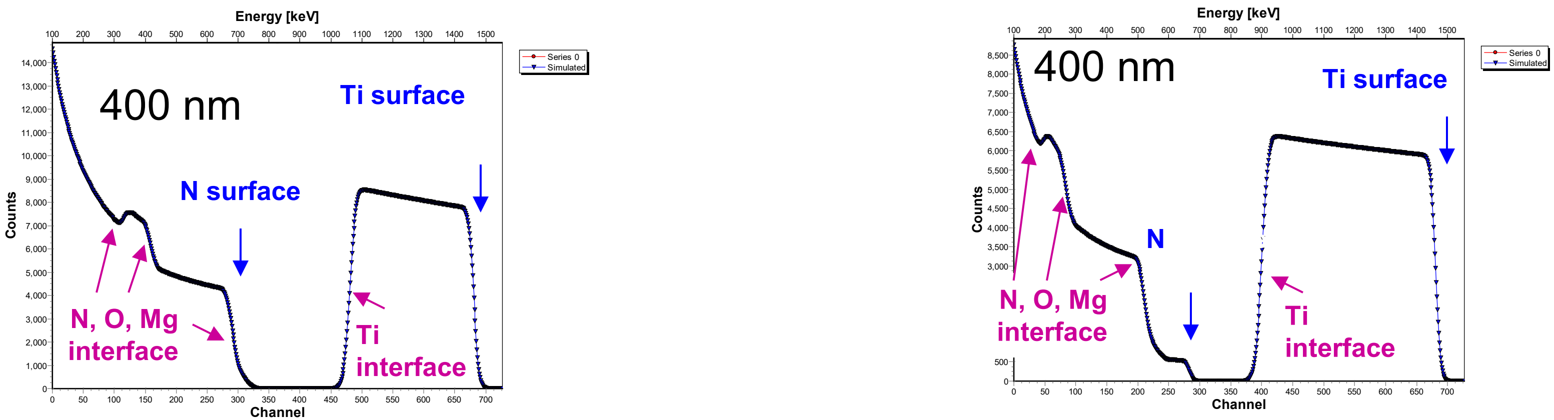

Scattered
D
N
15°
15°
Incident
He+


400 nm
N surface
N, O, Mg
interface
Ti
interface
Ti surface
Energy [keV]
Counts
Channel


600 nm
N surface
N, O, Mg
interface
Ti
interface
Ti surface
Energy [keV]
Counts
Channel

TiN/MgO



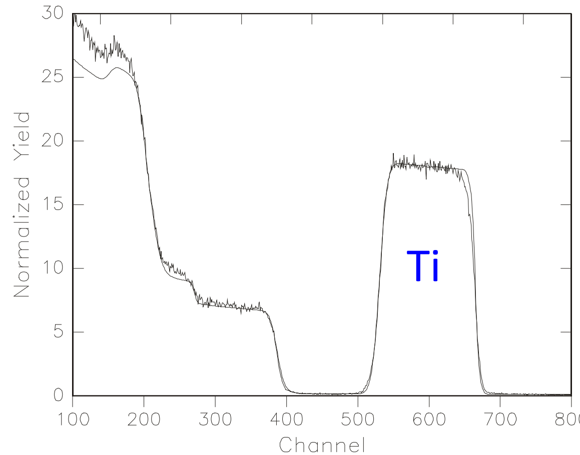


Surface peaks do not change position with incident angle

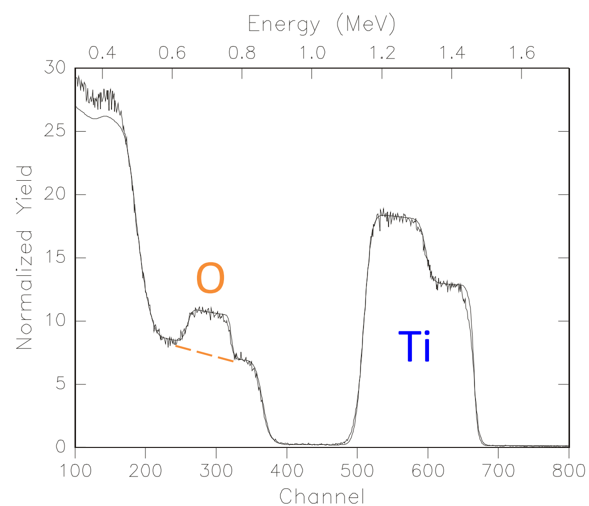
RBS: Oxidation Behavior

TiN/SiO_2

As-deposited



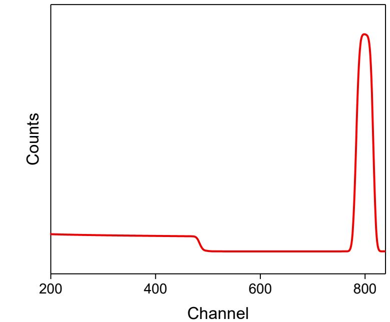
Annealed in atmosphere for 12 min at $T_a = 600$ °C

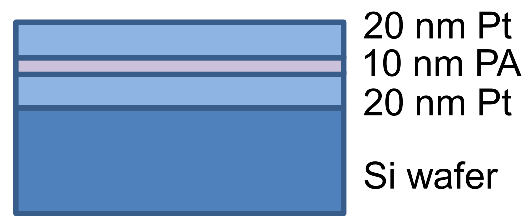


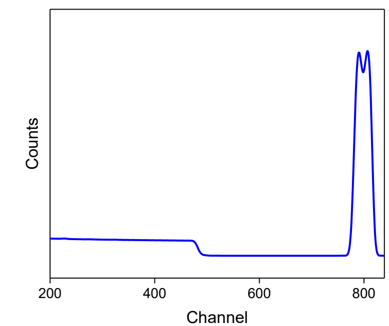
Experimental spectra and simulated spectra by RUMP

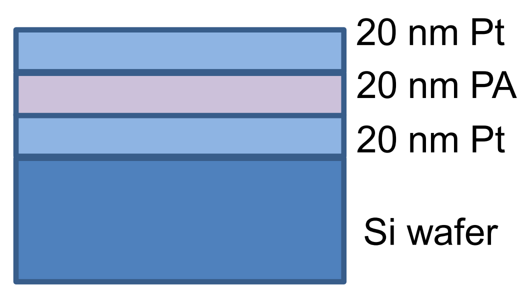
Areal mass density by RBS

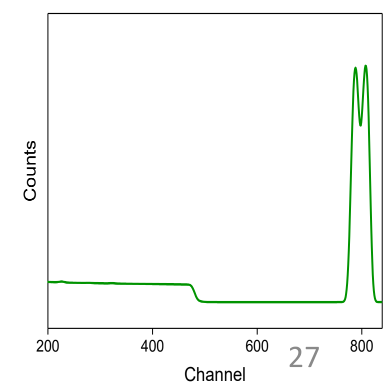
- Free-standing polyamide films are too thin to give sufficient signal in the RBS.
- Use the added stopping power of the polymer to split the Pt peak in the RBS spectrum.







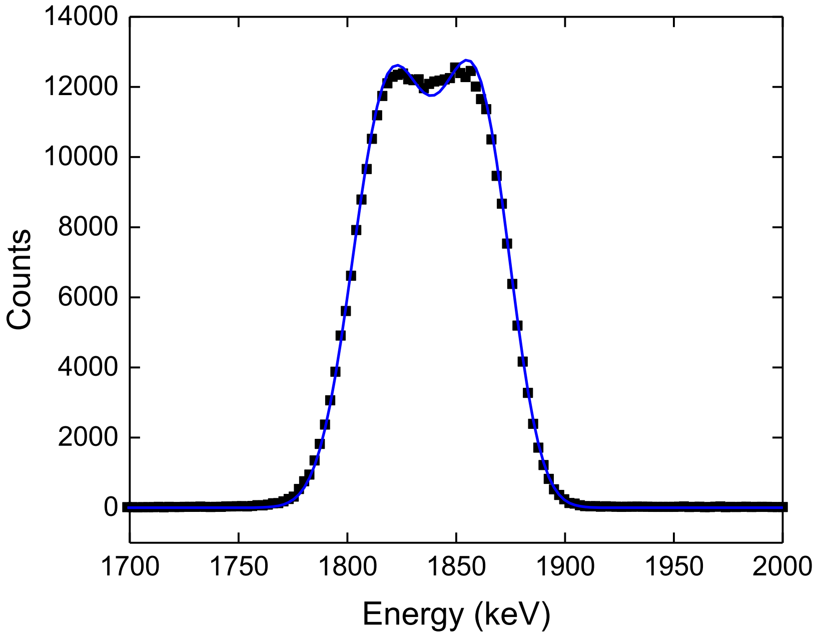


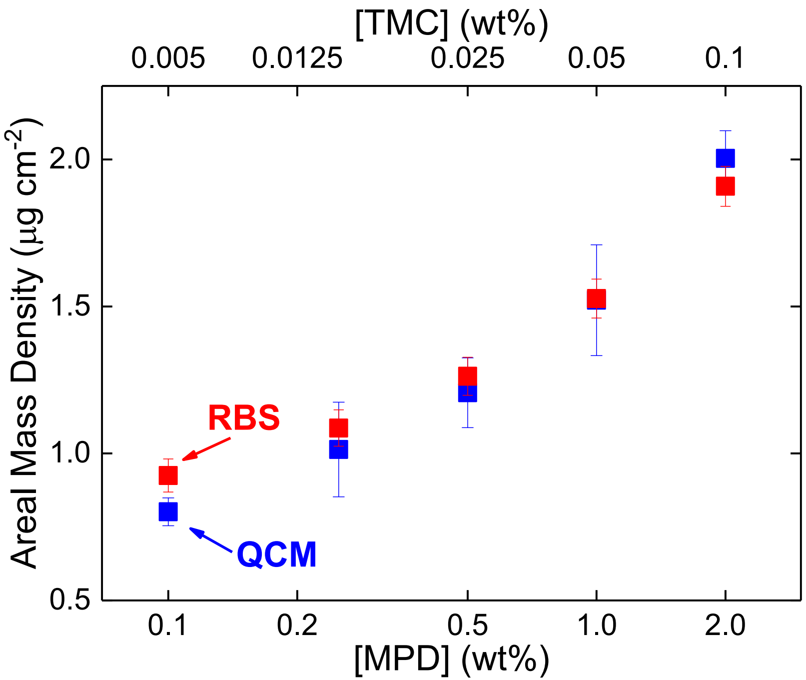


JM Dennison, X Xie, CJ Murphy, DG Cahill - ACS Applied Nano Materials, 2018

Areal mass density by RBS

0.005 wt% TMC, 0.1 wt % MPD





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

Elastic Recoil Detection

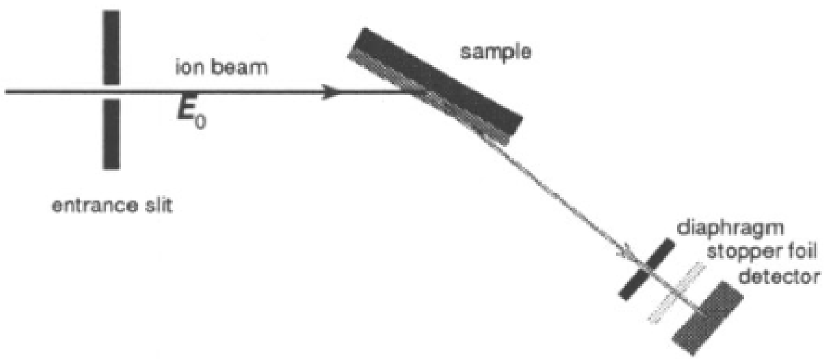
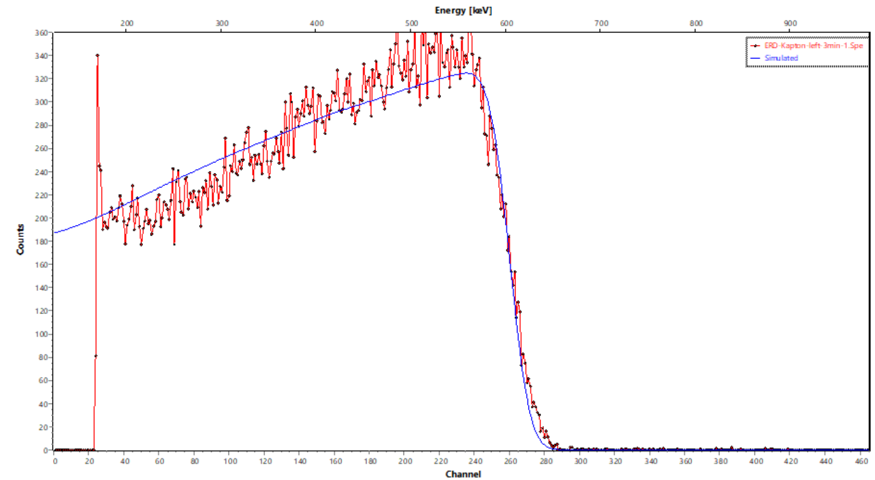


Figure 3. Schematic view of ERD in the conventional set-up.

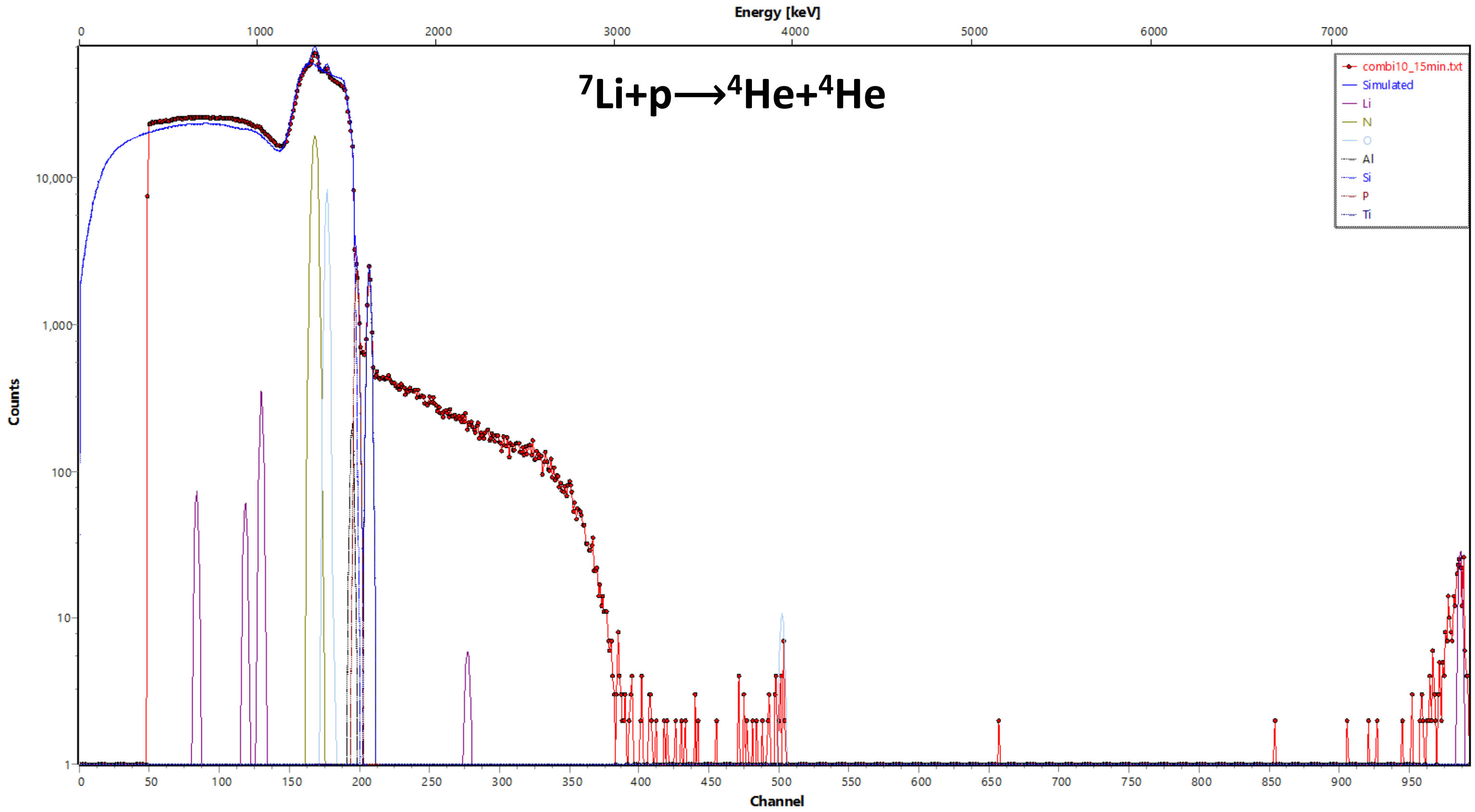
W M Arnold Bik and F H P M Habraken 1993
Rep. Prog. Phys. 56 859



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

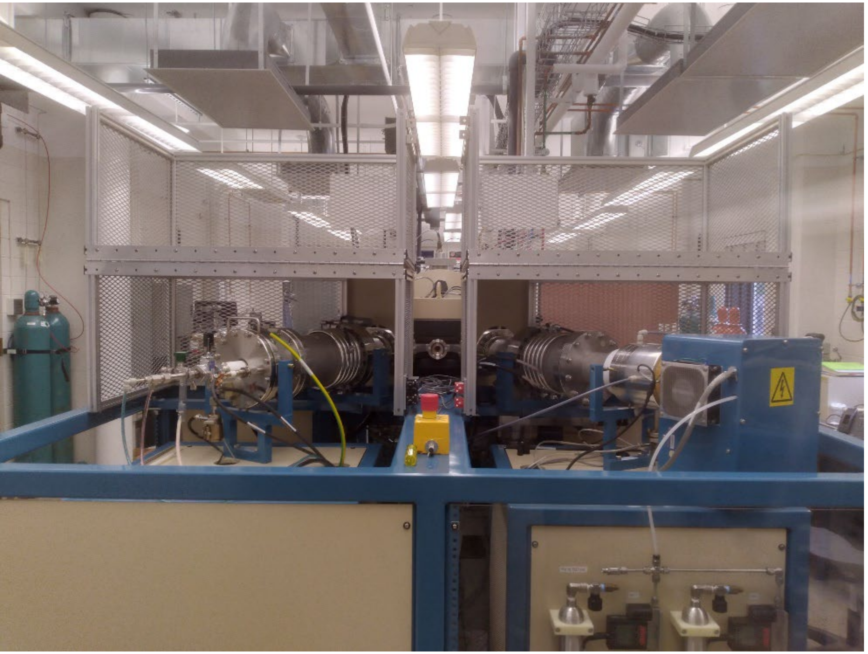
Additional Analytical Capabilities

Nuclear Reaction Analysis



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

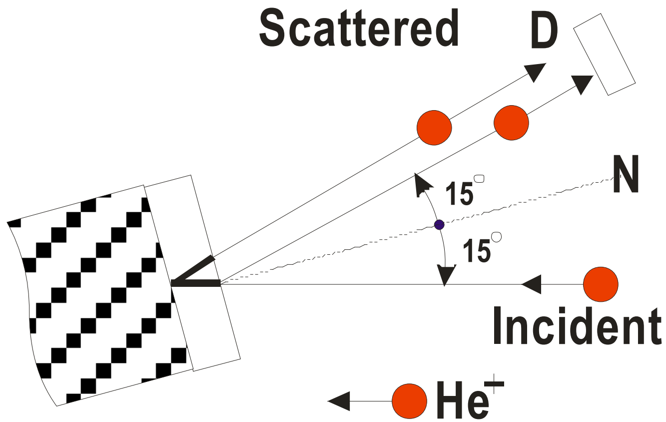
Ion Irradiation



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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