AP 5301/8301

Instrumental Methods of Analysis and Laboratory

Lecture 11

Ion Beam Analysis

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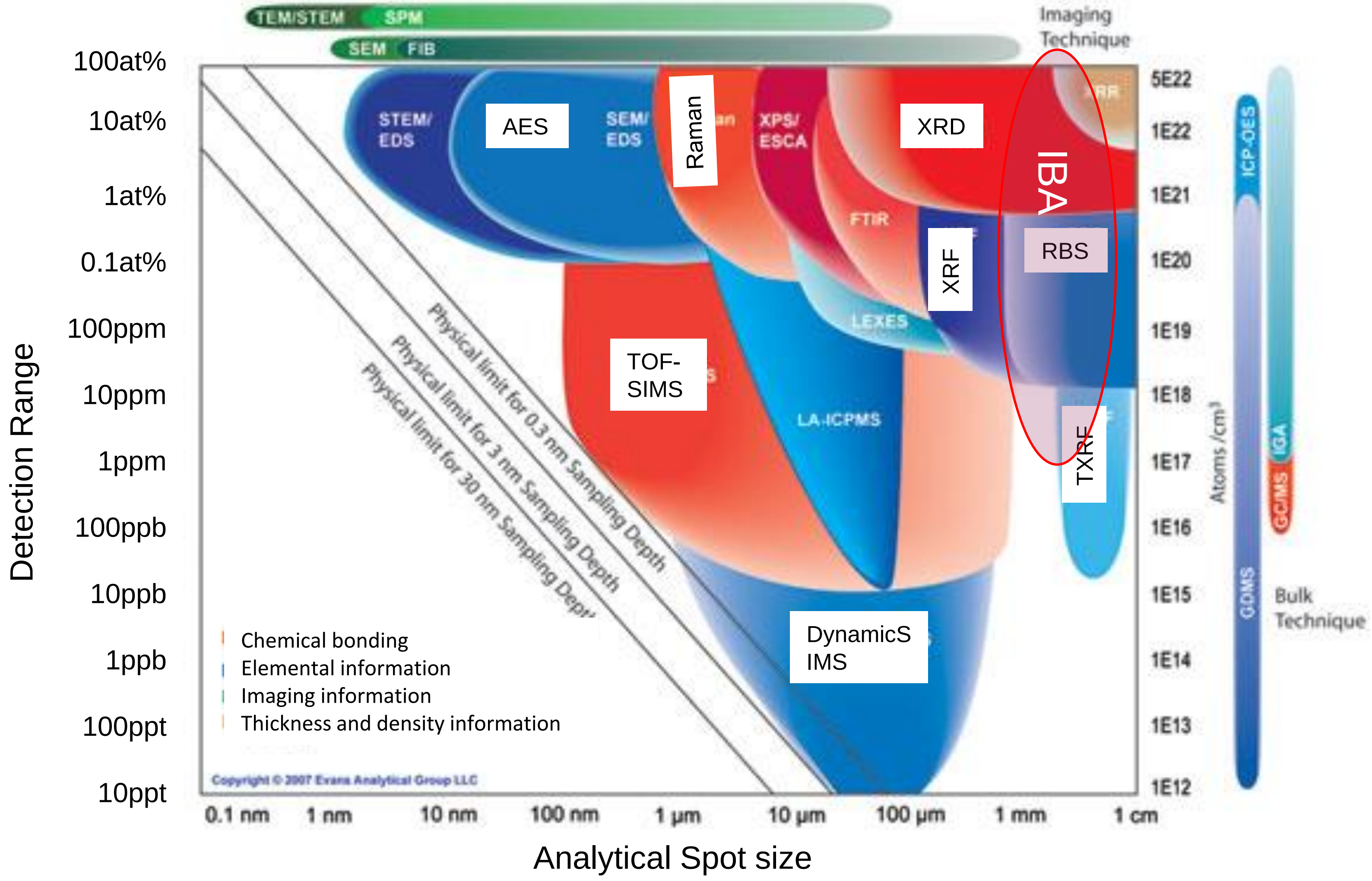
Lecture 8: outline

- Introduction
  - Ion Beam Analysis: an overview
- Rutherford backscattering spectrometry (RBS)
  - Introduction-history
  - Basic concepts of RBS
    - Kinematic factor (K)
    - Scattering cross-section
    - Depth scale
  - Quantitative thin film analysis
  - RBS data analysis
- Other IBA techniques
  - Hydrogen Forward Scattering
  - Particle induced x-ray emission (PIXE)
- Ion channeling
  - Minimum yield and critical angle
  - Dechanneling by defects
  - Impurity location

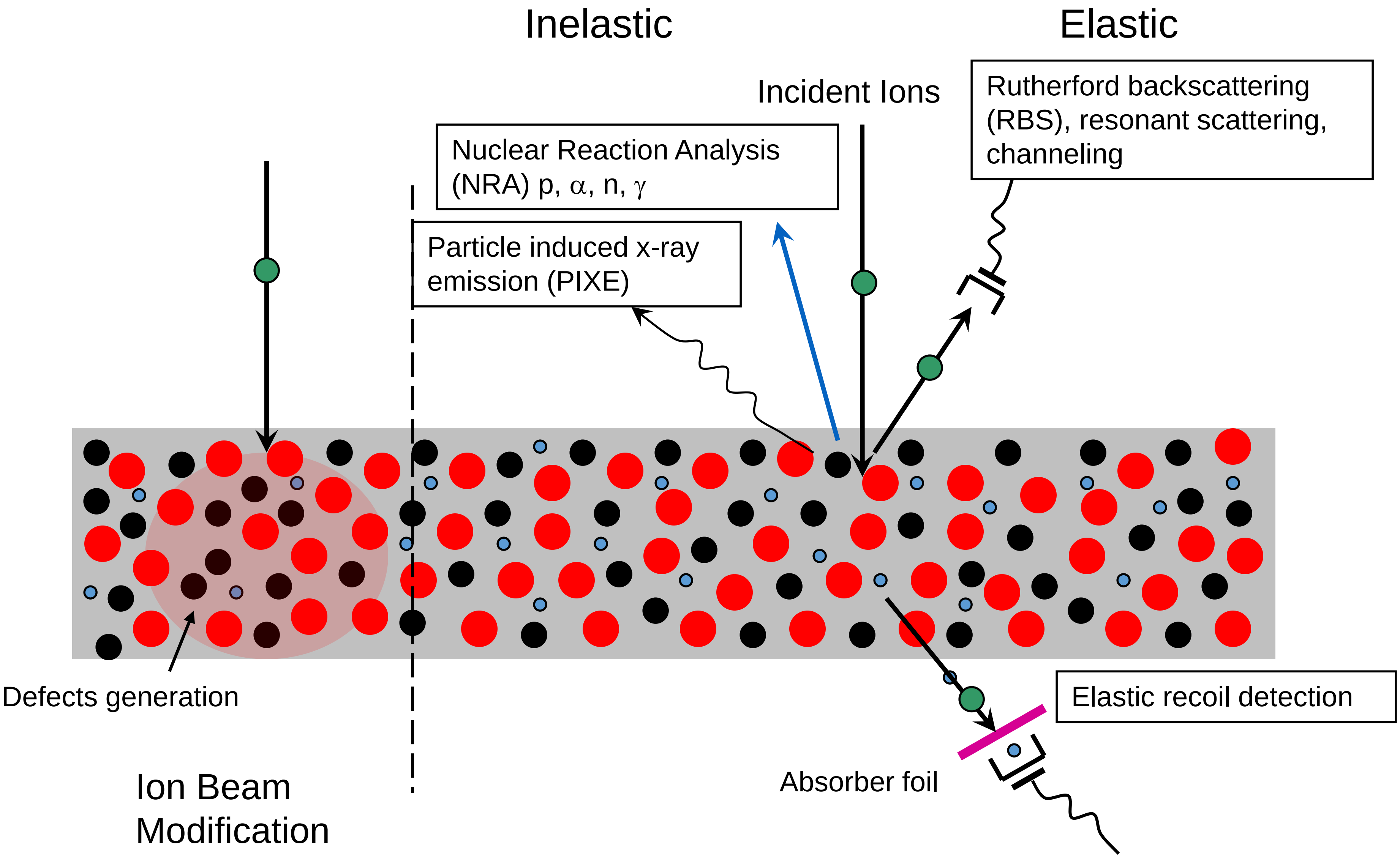
Analytical Techniques



But IBA is typically quantitative and depth sensitive

http://www.eaglabs.com

Ion Beam Analysis: an overview



Inelastic

Elastic

Incident Ions

Nuclear Reaction Analysis (NRA) p, α, n, γ

Particle induced x-ray emission (PIXE)

Rutherford backscattering (RBS), resonant scattering, channeling

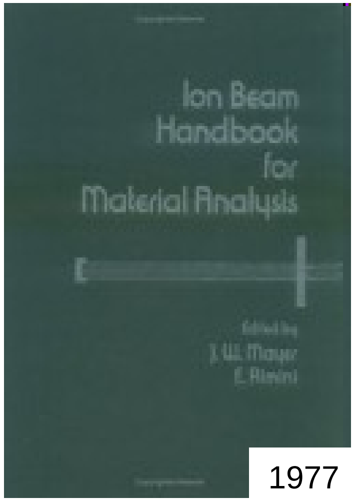
Defects generation

Elastic recoil detection

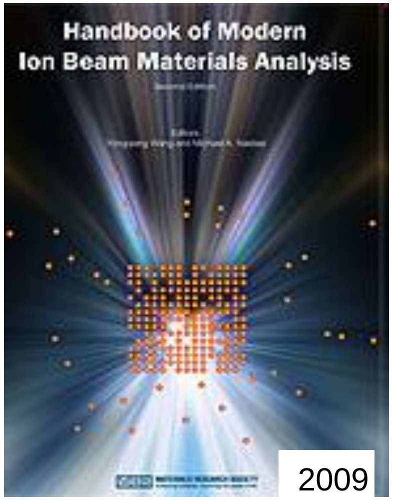
Absorber foil

Ion Beam Modification

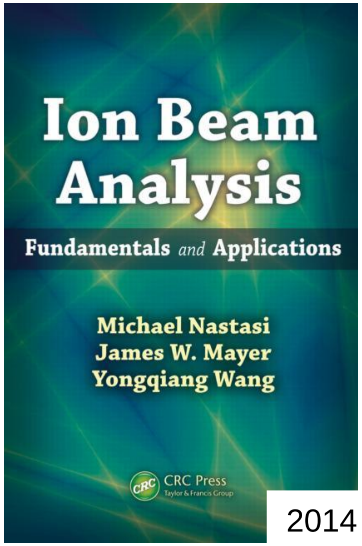
Ion Beam Analysis



1977



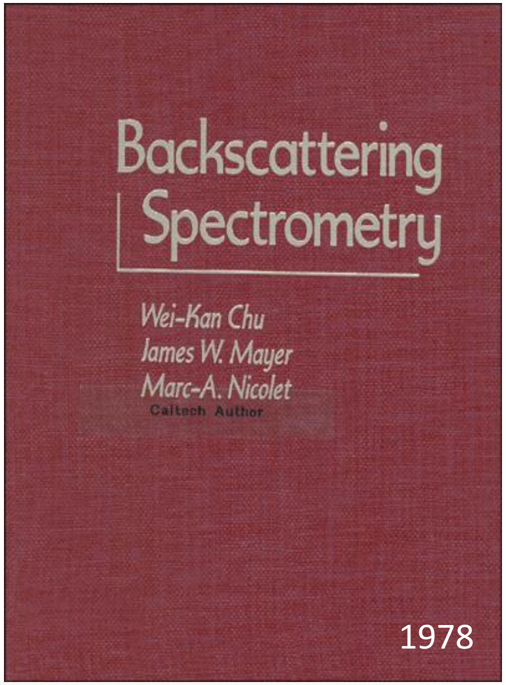
2009



2014

IBA 2015

PIXE 2017

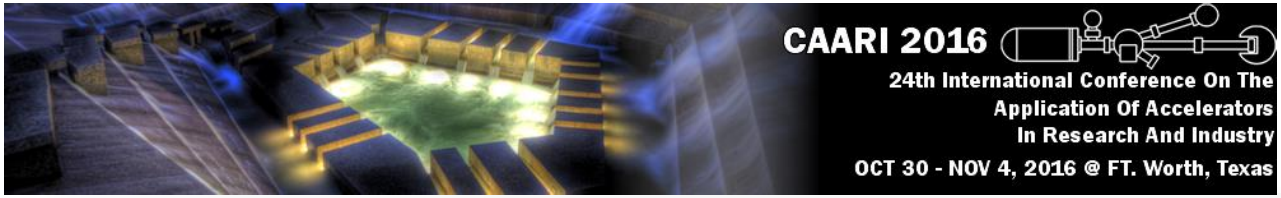


1978

ibmm 2016 New Zealand

20TH INTERNATIONAL CONFERENCE ON ION BEAM MODIFICATION OF MATERIALS

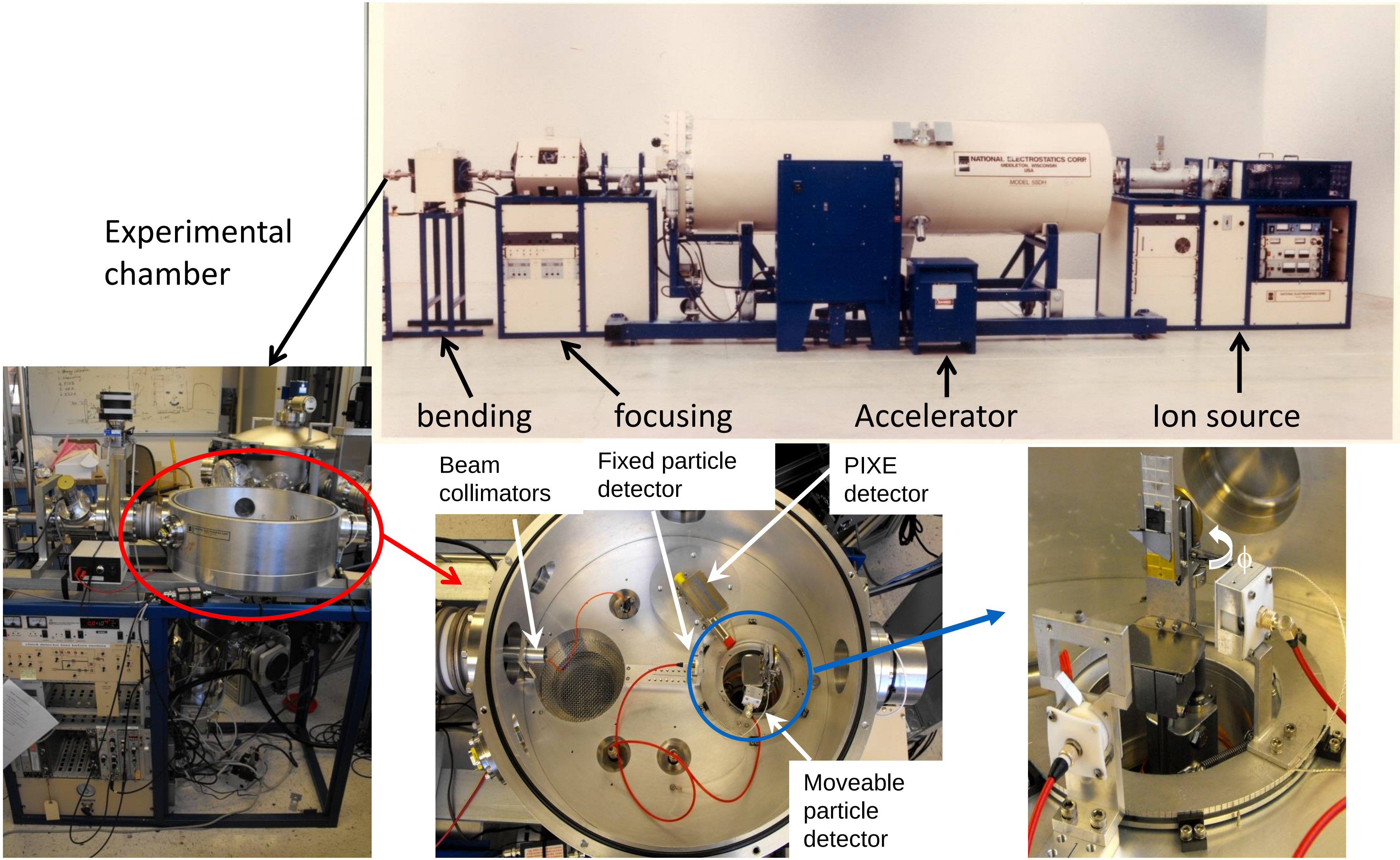
30 OCT–4 NOV 2016



Why IBA?

- Simple in principle
- Fast and direct
- Quantitative (without standard for RBS)
- Depth profiling without chemical or physical sectioning
- Non-destructive
- Wide range of elemental coverage
- No special specimen preparation required
- Can be applied to crystalline or amorphous materials
- Simultaneous analysis with various ion beam techniques (RBS, PIXE, NRA, channeling, etc.)
- Can obtain a lot of information in one measurement

A typical Ion Beam Analysis Facility



Experimental chamber

bending

focusing

Accelerator

Ion source

Beam collimators

Fixed particle detector

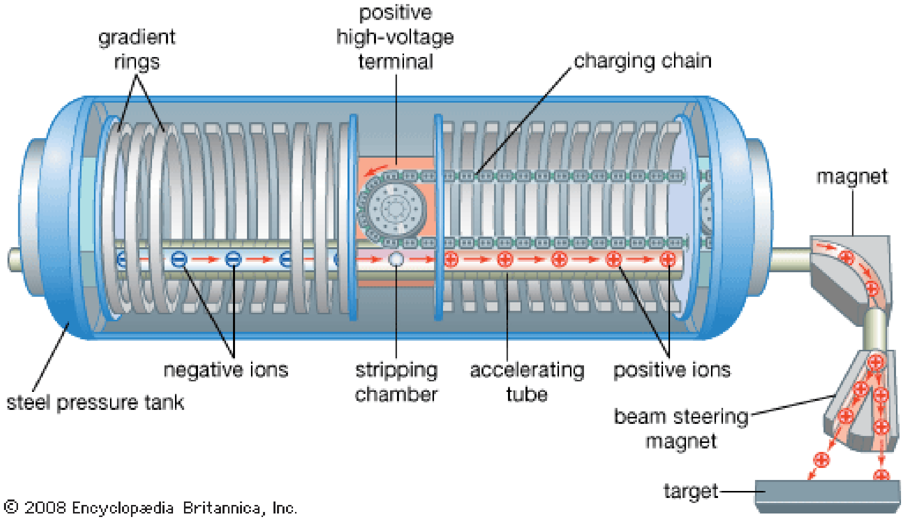
PIXE detector

Moveable particle detector

IBA Equipment: accelerator

Van de Graaff (single ended)

Tandem Pelletron



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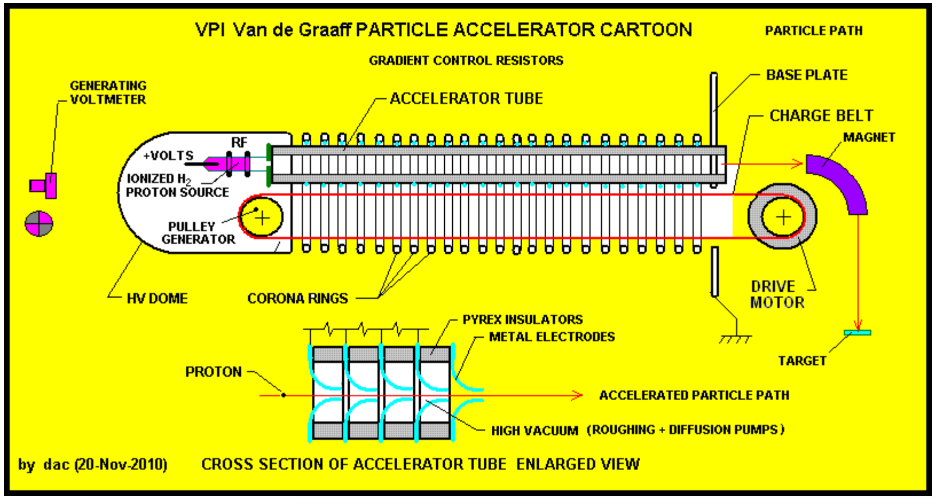
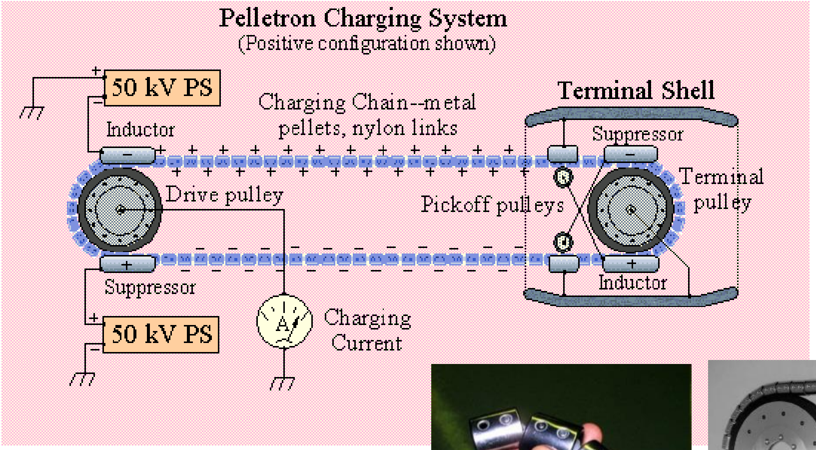
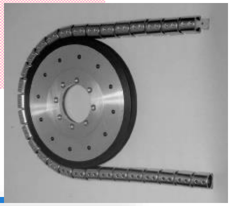
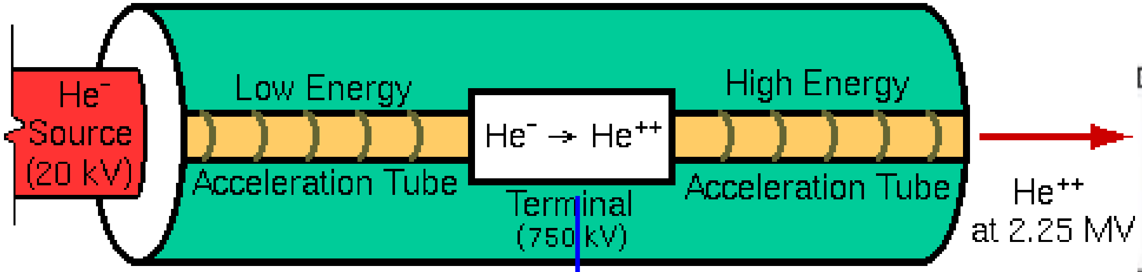


by dac (20-Nov-2010)

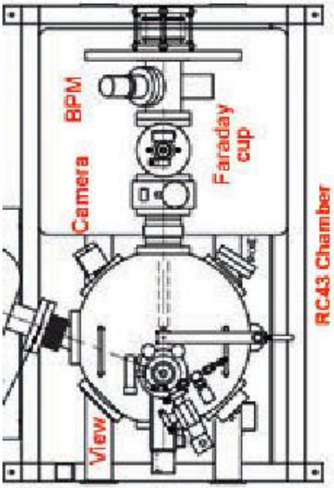


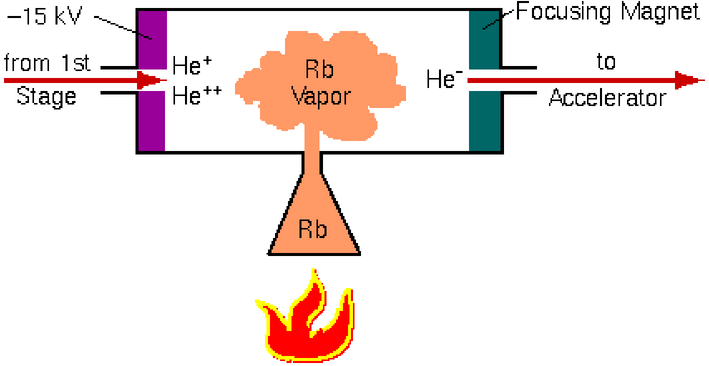


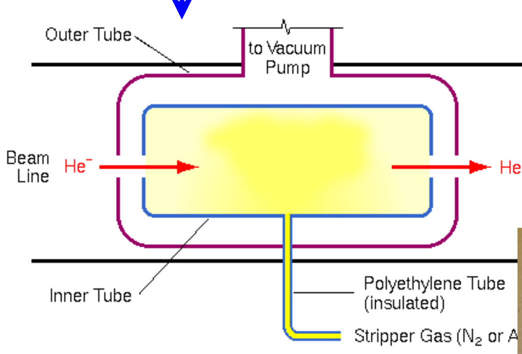
IBA Equipment: tandem pelletron

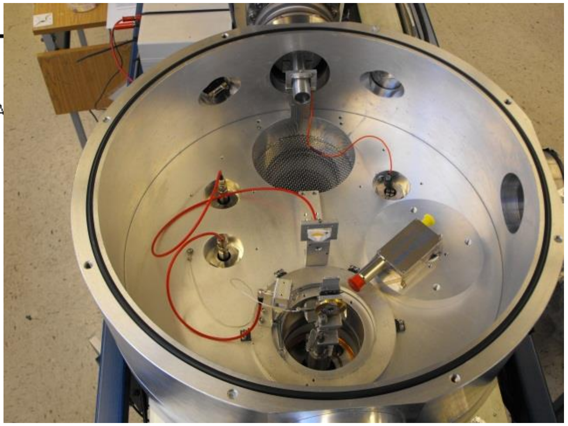


Tandem

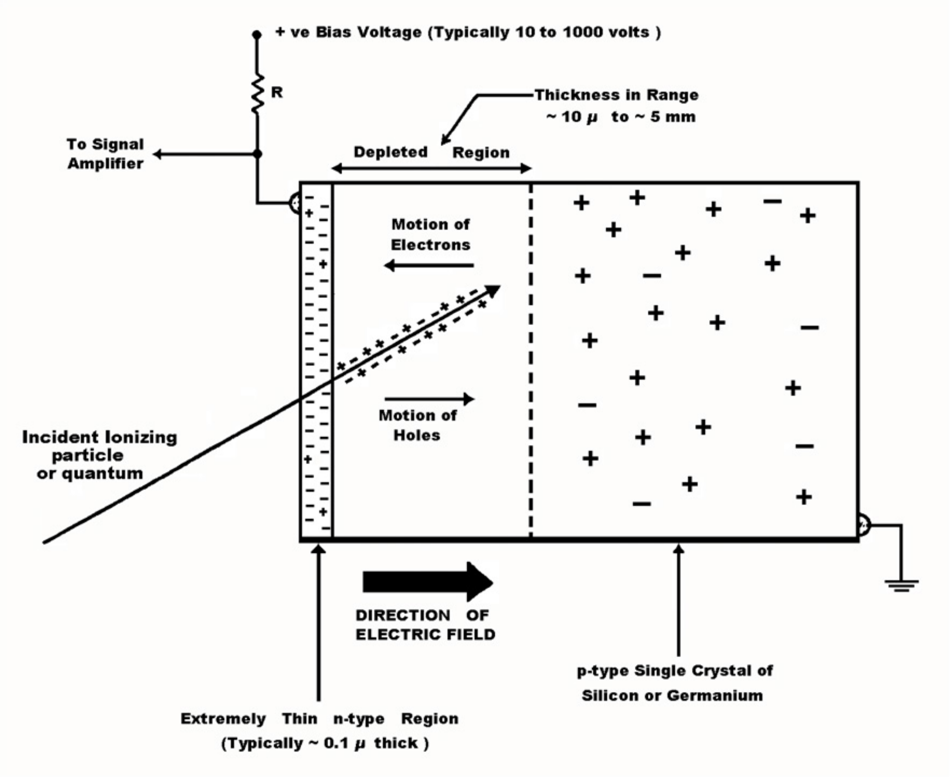


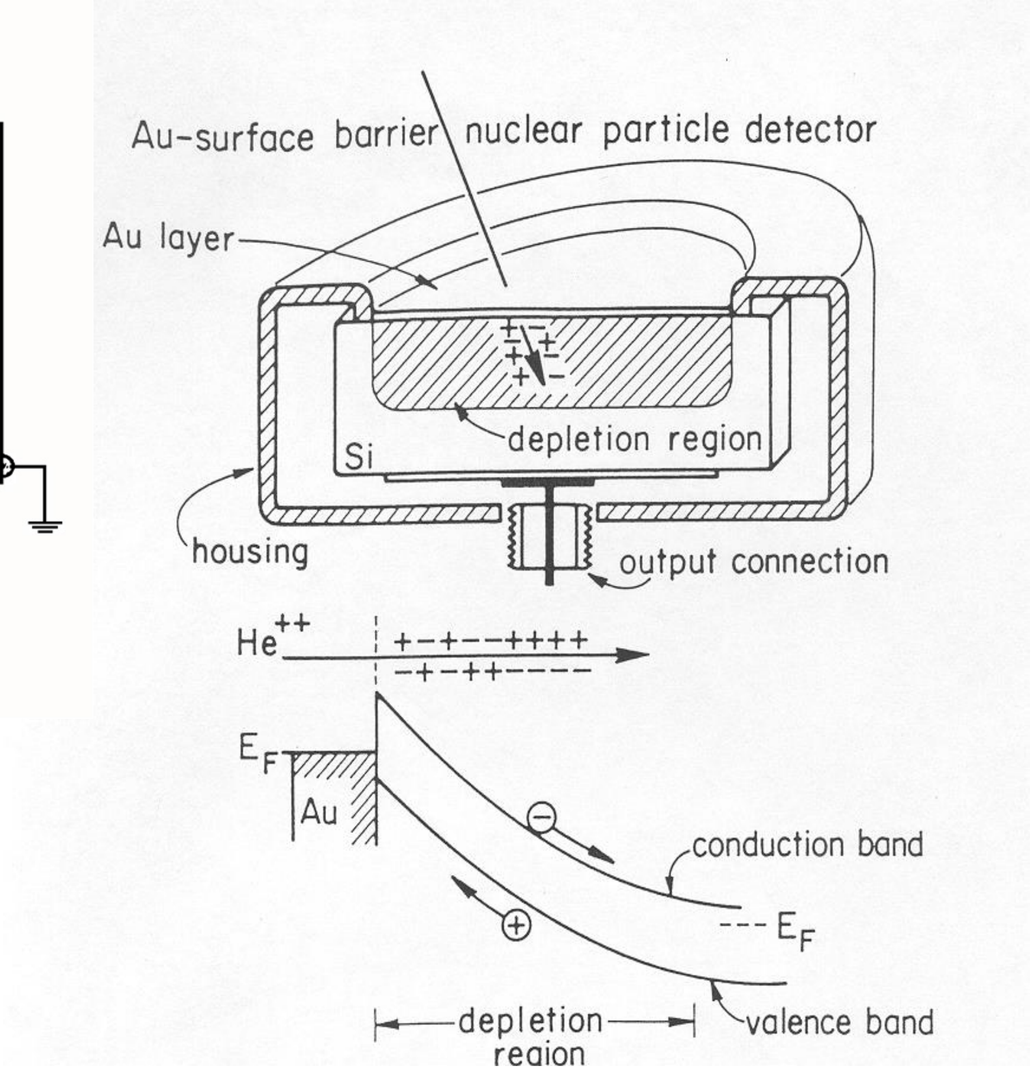




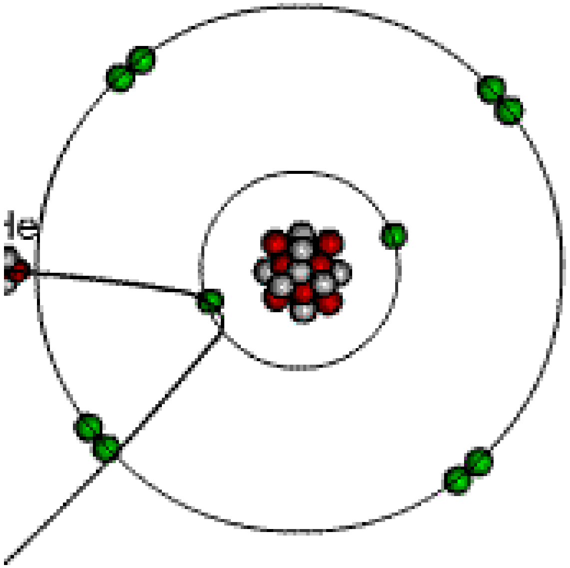


Equipment: particle detector





Rutherford Backscattering Spectrometry (RBS)



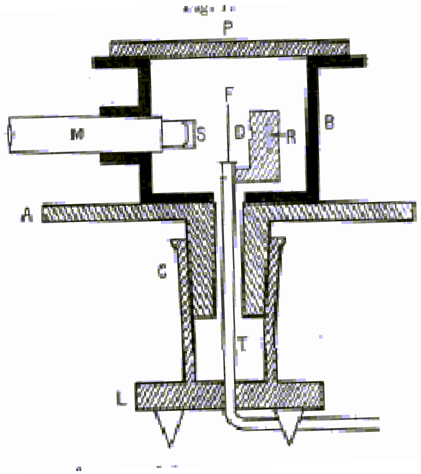
- Relatively simple physics
- Requires some experimental skills
- Requires some data simulation to obtain the most out of the spectrum
- The only quantitative and absolute method to determine
  - atomic concentration with no matrix effect
  - composition variation with depth
  - layer thickness
  - damage distribution and impurity lattice location

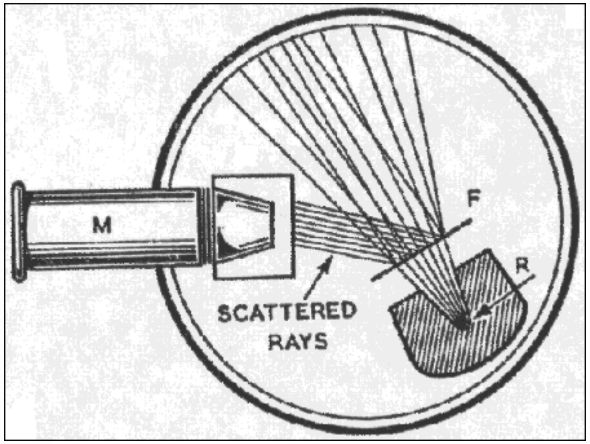
  of multi-elemental, multi-layered films

Rutherford Backscattering Spectrometry (RBS)

a brief history

The original experiment





Alpha particles at a thin gold foil experiment by Hans Geiger and Ernest Marsden in 1909.

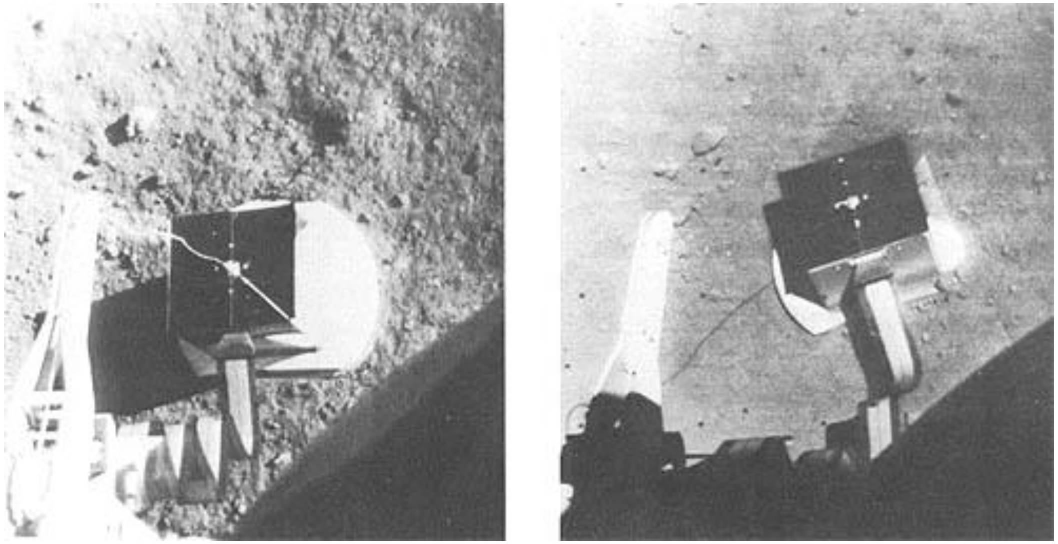
1) Almost all of the alpha particles went through the gold foil

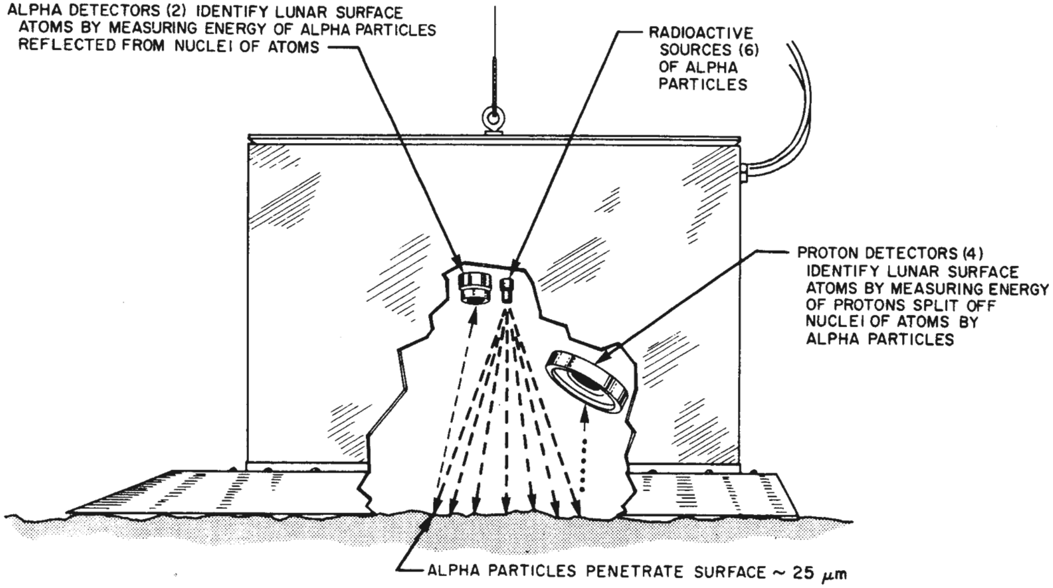
2) Some of the alpha particles were deflected only slightly, usually 2° or less.

3) A very, very few (1 in 8000 for platinum foil) alpha particles were turned through an angle of 90° or more.

"We shall suppose that for distances less that 10^{-12} cm the central charge and also the charge on the alpha particle may be supposed to be concentrated at a point." (1911)

RBS: The Surveyor V experiment





Surveyor V, first of its spacecraft family to obtain information about the chemical nature of the Moon's surface, landed in Mare Tranquillitatis on September 11, 1967.

"Surveyor V carried an instrument to determine the principal chemical elements of the lunar-surface material," explained ANTHONY TURKEVICH, Enrico Fermi institute and Chemistry Department, University of Chicago. "After landing, upon command from Earth, the instrument was lowered by a nylon cord to the surface of the Moon …"

General applications of RBS

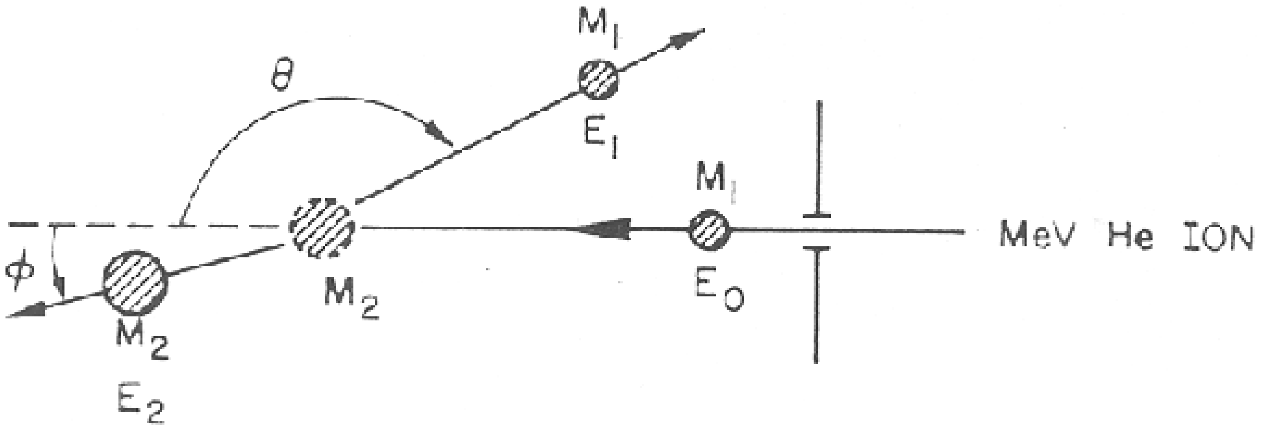
- Quantitative analysis of thin films
    - thickness, composition, uniformity in depth
    - solid state reactions
    - interdiffusion
- Crystalline perfection of homo- and heteroepitaxial thin films
- Quantitative measurements of impurities in substrates
- Defect distribution in single-crystal samples
- Surface atom relaxation in single crystals
- Lattice location of impurities in single crystals

RBS: basic concepts

- Kinematic factor: elastic energy transfer from a projectile to a target atom can be calculated from collision kinematics
    - mass determination
- Scattering cross-section: the probability of the elastic collision between the projectile and target atoms can be calculated
    - quantitative analysis of atomic composition
- Energy Loss: inelastic energy loss of the projectile ions through the target
    - perception of depth

These allow RBS analysis to give quantitative depth distribution of targets with different masses

Kinematic factor: *K*



Conservation of energy :

$$\frac{1}{2}m_1v^2 = \frac{1}{2}m_1{v_1}^2 + \frac{1}{2}m_2{v_2}^2$$

Conservation of momentum:

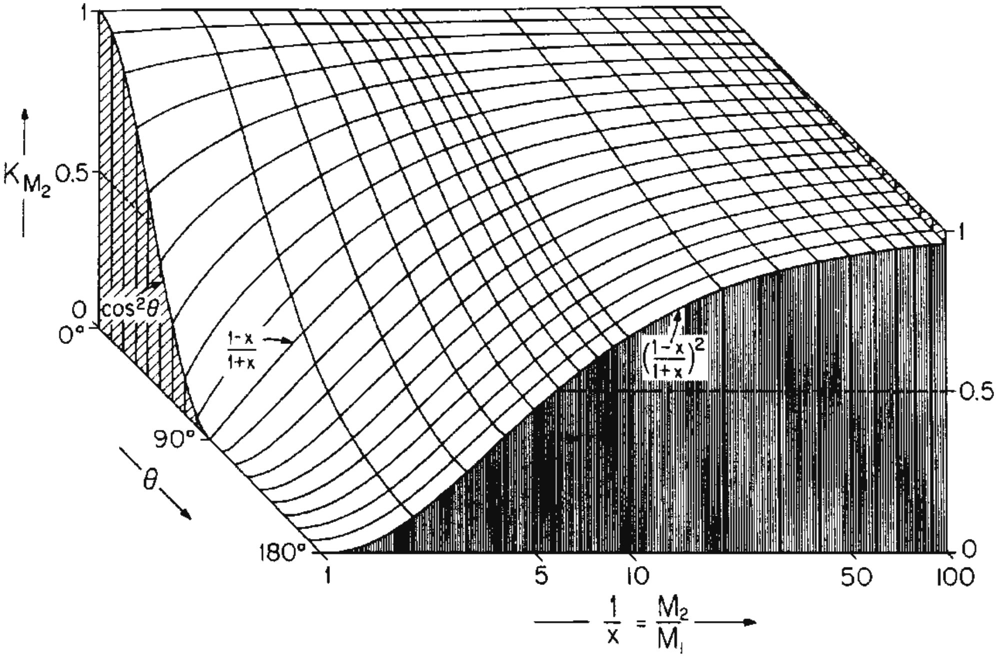
$$m_1v = m_1v_1\cos\theta \ + m_2v_2\cos\phi$$

$$m_1v_1\sin\theta = m_2v_2\sin\phi$$

$$\boxed{K_{m_2} = \frac{E_1}{E_o} = \left[\frac{\sqrt{(m_2^2 - m_1^2\sin^2\theta)} + m_1\cos\theta}{(m_2 + m_1)}\right]^2 = K\left(\theta, m_2, m_1\right)}$$

Kinematic Factor

$$K_{m_2} = \frac{E_1}{E_o} = \left[\frac{\sqrt{(m_2^2 - m_1^2 \sin^2 \theta)} + m_1 \cos\theta}{(m_2 + m_1)} \right]^2$$



$$K_{m_2}(\theta = 180^o) = \left[\frac{(m_2 - m_1)}{(m_2 + m_1)} \right]^2$$

$$K_{m_2}(\theta = 90^o) = \frac{(m_2 - m_1)}{(m_2 + m_1)}$$

When $m_2 >> m_1$:

$$K_{m_2}(\theta = 180^o) \sim 1$$

Element identification

2.5 MeV He ion with θ=170°

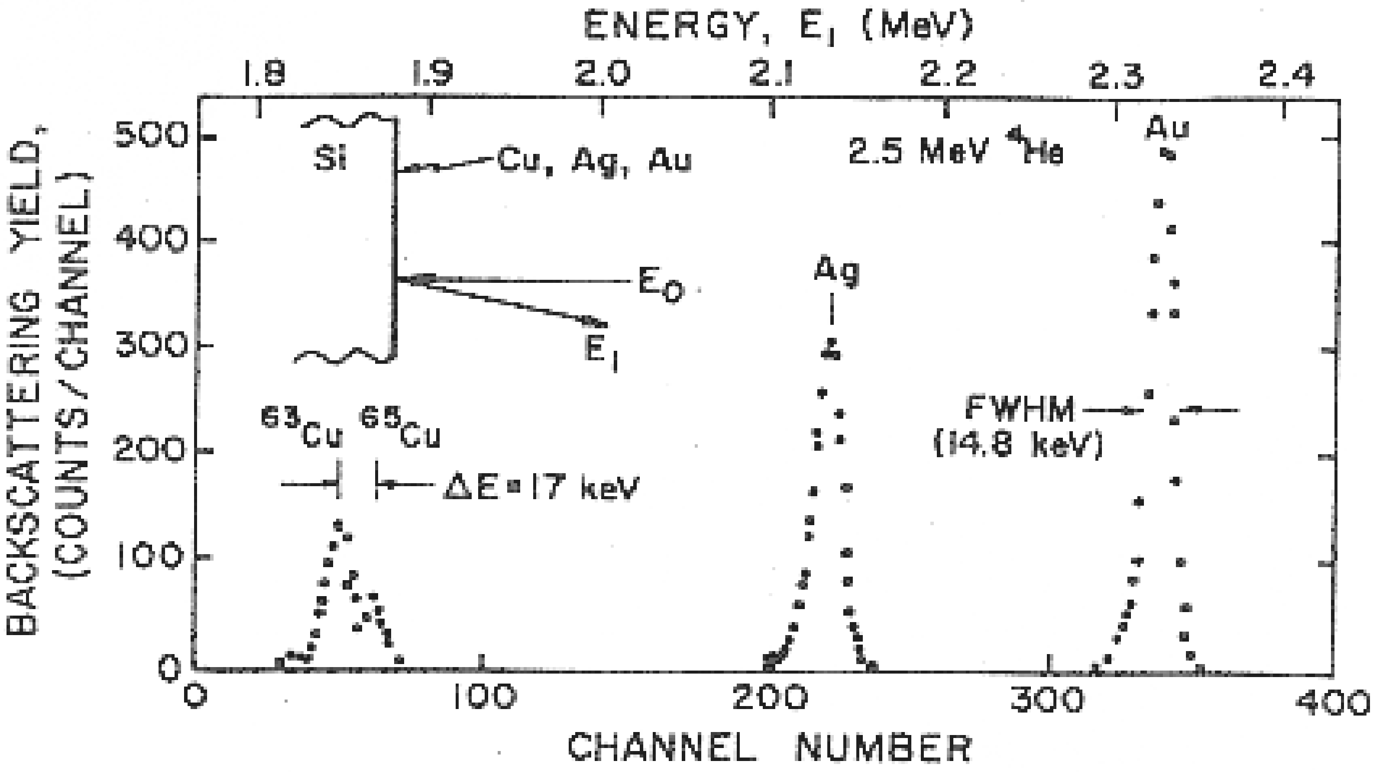
$K(^{197}Au) = 0.923$

$K(^{109}Ag) = 0.864$

$K(^{107}Ag) = 0.862$

$K(^{65}Cu) = 0.783$

$K(^{63}Cu) = 0.777$

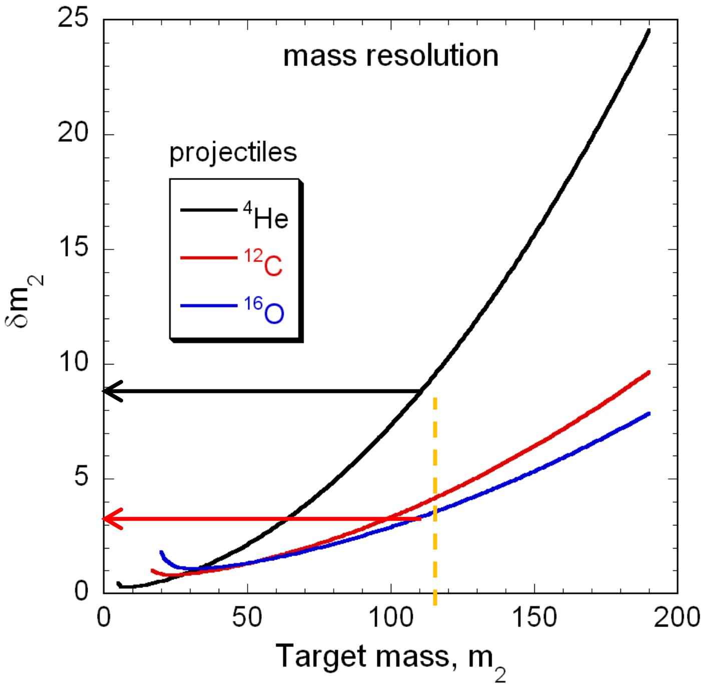


Mass Resolution, δm_2

For 180º scattering:

$$K_{m_2} = \frac{E_1}{E_0} = \left[\frac{(m_2 - m_1)}{(m_2 + m_1)}\right]^2$$

$$\frac{\delta E_1}{E_0} = \delta \frac{(m_2 - m_1)^2}{(m_1 + m_2)^2}$$

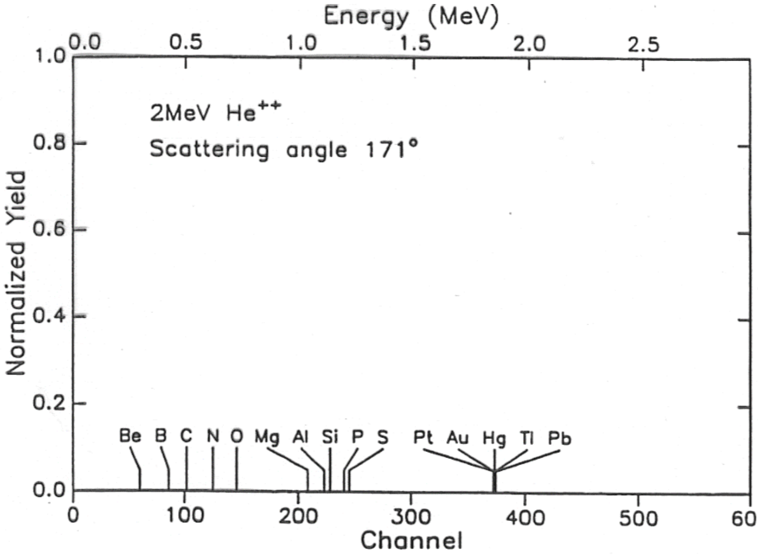


For a fixed $\delta E_1/E_0$ (~0.01), heavier projectiles result in better mass resolution

However, δE_1 for heavier projectiles is higher

Mass Resolution: examples

With system energy resolution δE = 20keV and E_0=2MeV



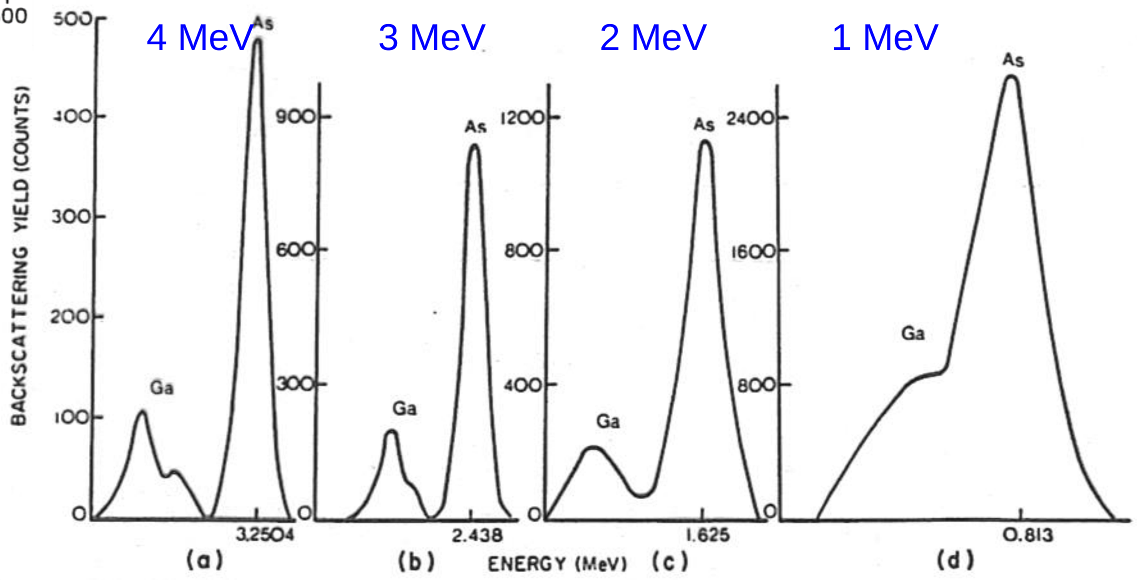
For m_2=40 $$\delta m_2 = \frac{(40+4)^3}{4\times 4(40-4)} \bullet \frac{20}{2000} = 1.48 a.m.u.$$

For m_2 = 70 $$\delta m_2 = \frac{(70+4)^3}{4\times 4(70-4)} \bullet \frac{20}{2000} = 3.84 a.m.u.$$

Isotopes of Ga (68.9 and 70.9 a.m.u.) cannot be resolved

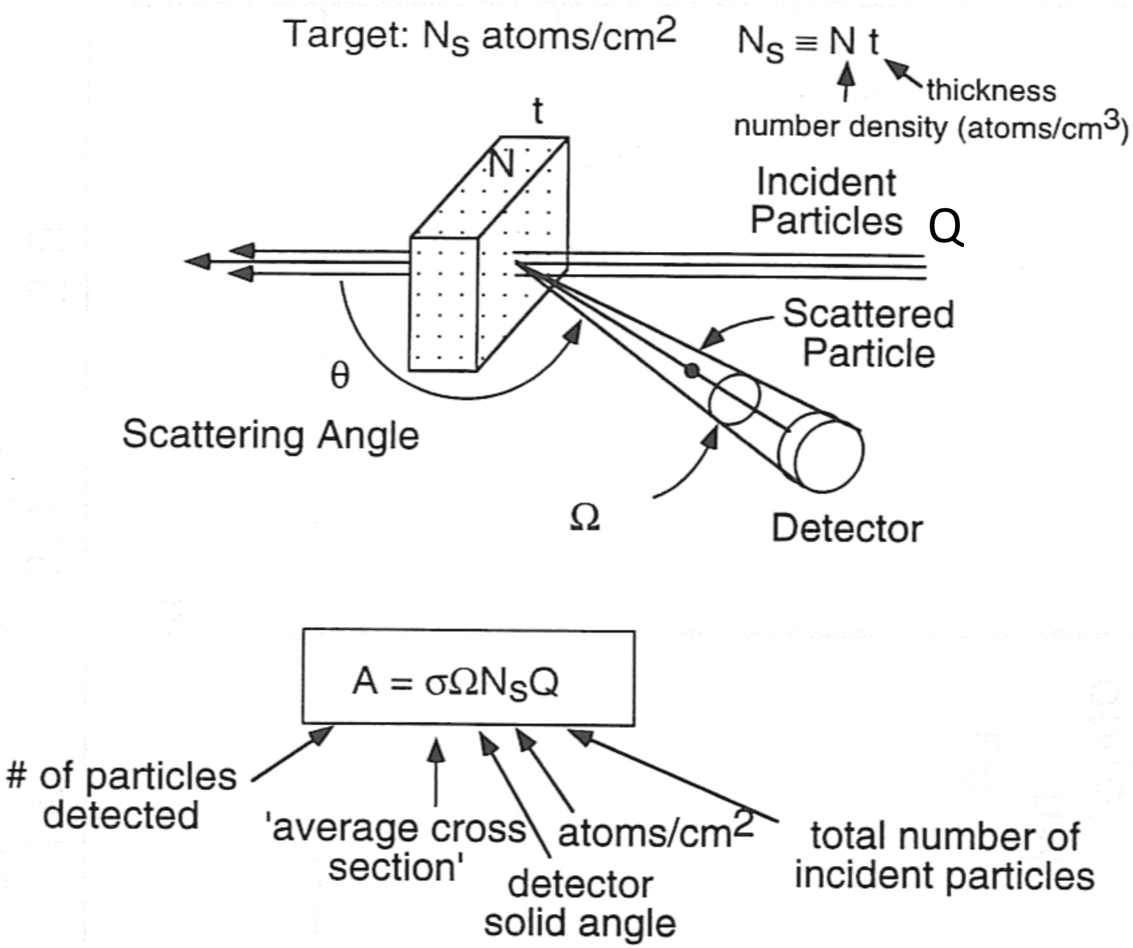
We can also improve mass resolution by increasing E_o

$$\therefore \delta m_2 = \frac{\left(m_2+m_1\right)^3}{4m_1\left(m_2-m_1\right)} \frac{\delta E_1}{E_0}$$



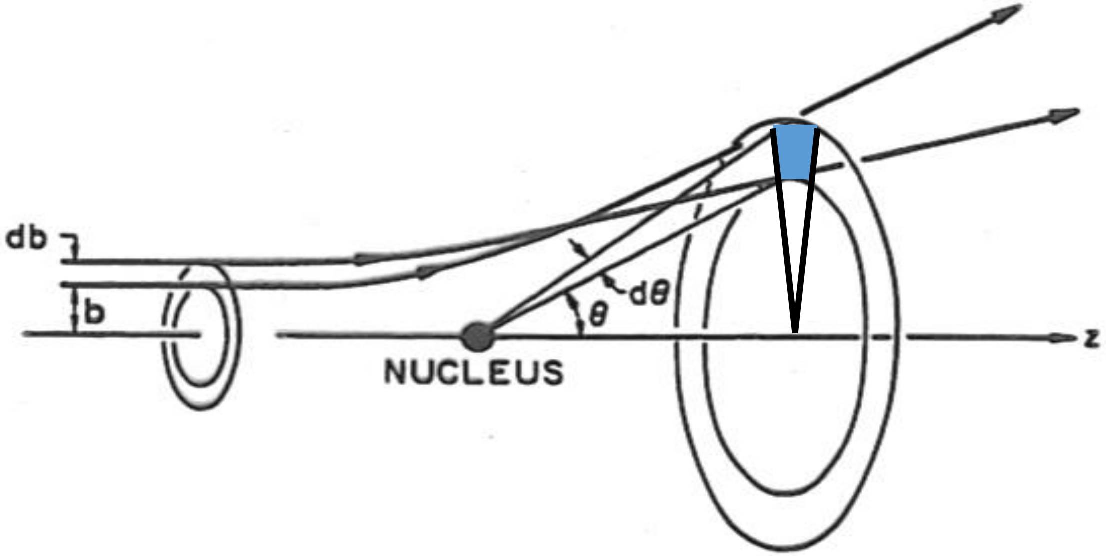
RBS Quantification

Backscattering Yield



- For a given incident number of particles Q, a greater amount of an element present (N_s) should result in a greater number of particles scattered.
- Thus we need to know how often scattering events should be detected (A) at a characteristic energy ($E = KE_0$) and angle θ, within our detector's window of solid angle Ω.

Scattering cross-section



If particles are coming in with impact parameters between b and b +db , they will be scattered through angles between θ and θ+dθ. For central forces, we have circular symmetry.

$$2\pi b db = -\sigma(\theta)\cdot 2\pi \sin\theta d\theta$$

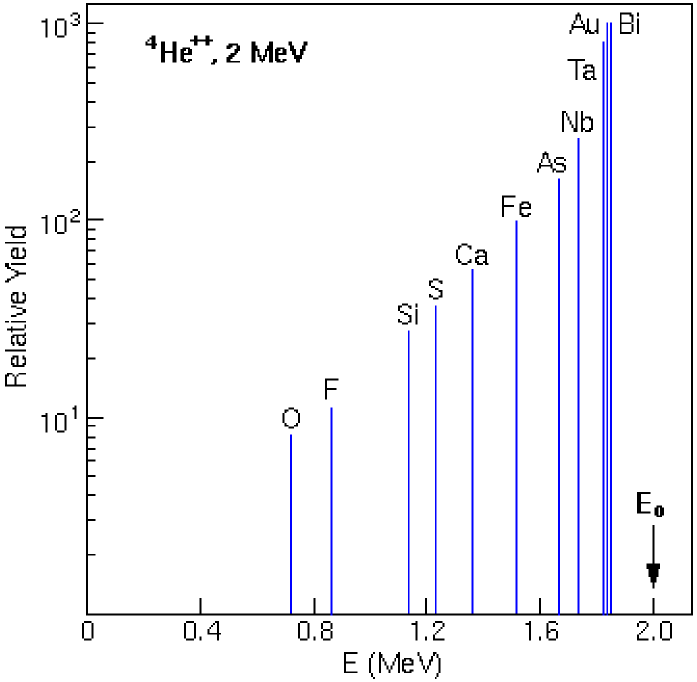
Rutherford cross-section:

$$\frac{d\sigma}{d\Omega}=\left(\frac{Z_1Z_2e^2}{2E_o}\right)^2\frac{\left[\cos\theta+(1-A^2\sin^2\theta)^{1/2}\right]^2}{\sin^4\left(\frac{\theta}{2}\right)(1-A^2\sin^2\theta)^{1/2}}\sim\left(\frac{Z_1Z_2}{E_o}\right)^2 \qquad A=\frac{m_1}{m_2}$$

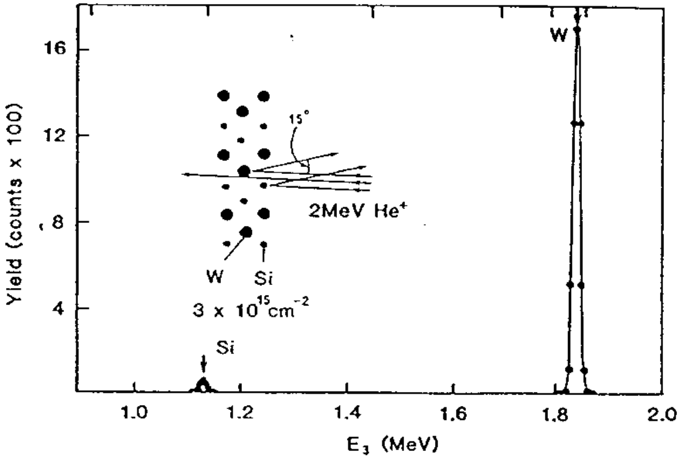
Scattering Yield

$$Yield, Y \propto \sigma(\theta) = \left(\frac{Z_1 Z_2 e^2}{2E_0}\right)^2 \frac{\left[\cos\theta + \left(1 - A^2 \sin^2\theta\right)^{1/2}\right]^2}{\sin^4\frac{\theta}{2}\left(1 - A^2 \sin^2\theta\right)^{1/2}}$$

$$\propto \left(\frac{Z_1 Z_1}{E_0}\right)^2 \sim 10^{-24}\, cm^2 [barn]$$



Example:



Mixed Si and W target analzed by a 2MeV He ion beam at 165° scattering angle.

$\sigma(Si)=2.5x10^{-25}cm^2/str$

$\sigma(W)=7.4x10^{-24}cm^2/str$

Total incident ions $Q=1.5x10^{14}$ ions

$\Omega=1.8$mstr

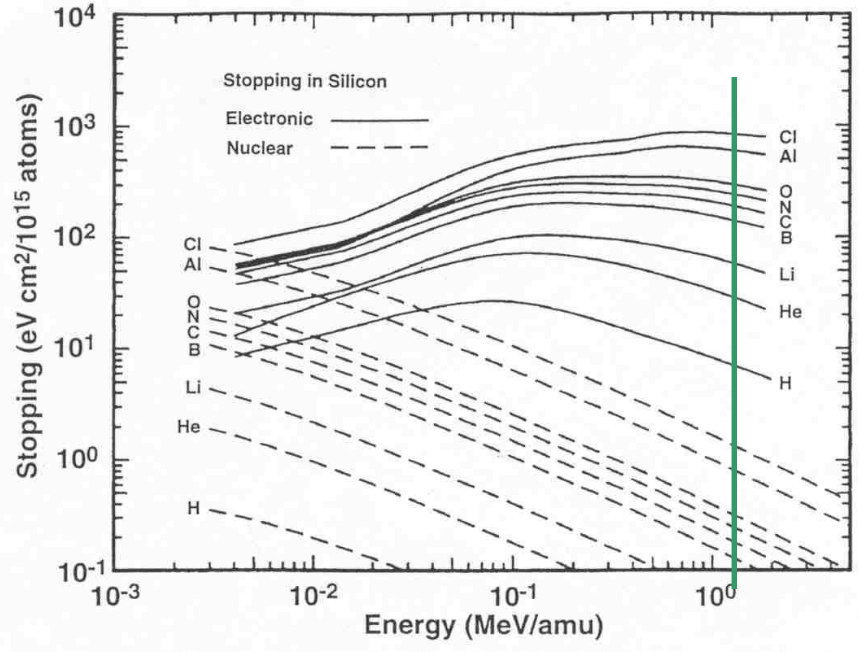
Area under Si, A(Si)=200 counts

Area under W, A(W)=6000 counts

$(Nt)_{Si}=3x10^{15}atoms/cm^2$

$(Nt)_W=3x10^{15}atoms/cm^2$

Energy Loss



Electronic stopping $\left.\frac{dE}{dx}\right|_{ele}$

Nuclear Stopping $\left.\frac{dE}{dx}\right|_{nucl}$

When an He or H ion moves through matter, it loses energy through

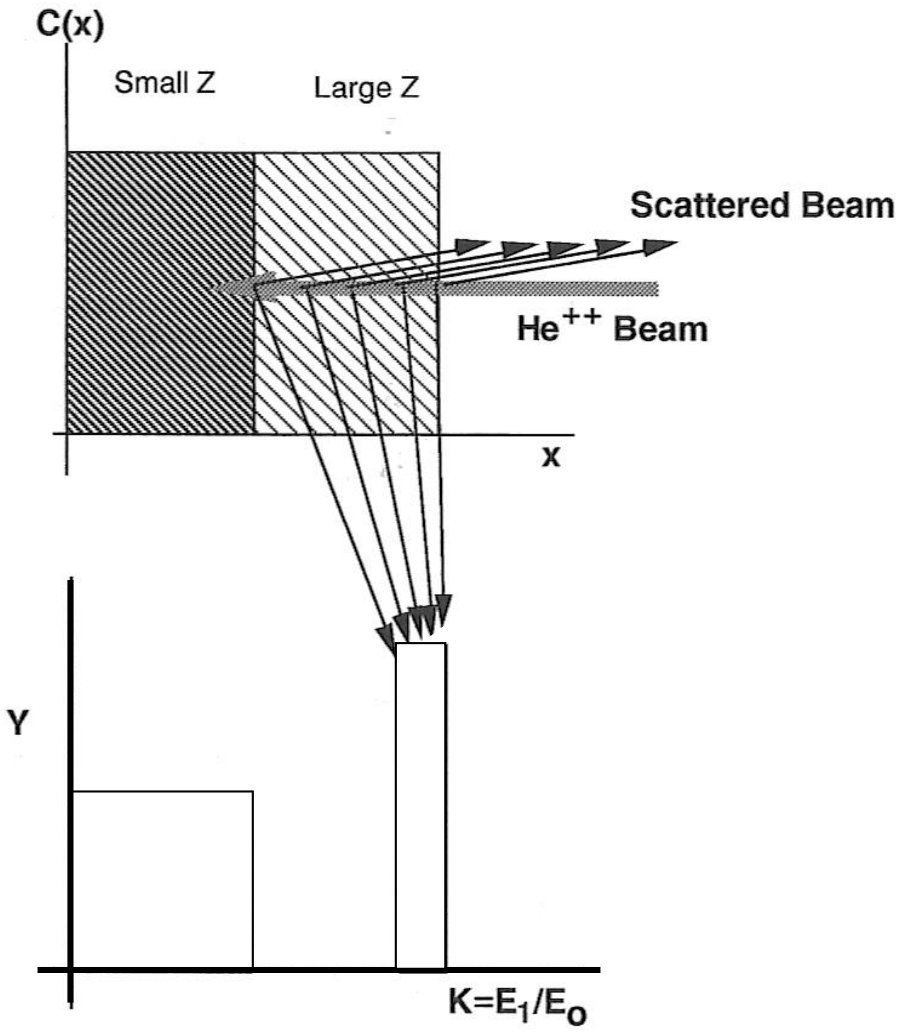
- interactions with e$^-$ by raising them to excited states or even ionizing them.
- Direct ion-nuclei scattering

Since the radii of atomic nuclei are so small, interactions with nuclei may be neglected

$$\boxed{\left.\frac{dE}{dx}\right|_{total} = \left.\frac{dE}{dx}\right|_{ele} + \left.\frac{dE}{dx}\right|_{nucl} \approx \left.\frac{dE}{dx}\right|_{ele}}$$

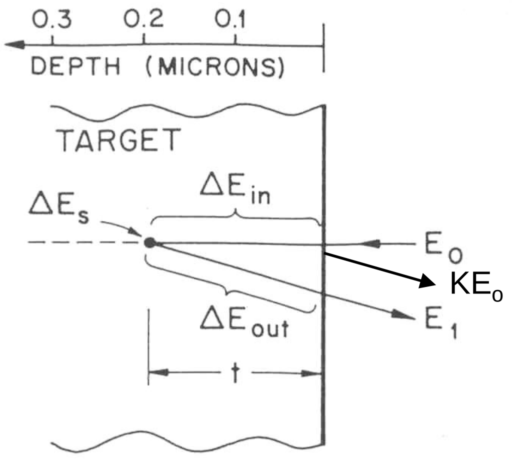
How to read a typical RBS spectrum

A thin film on a light substrate



- Most projectile ions experience electronic stopping that results in a gradual reduction of the particle's kinetic energy (dE/dx).
- At the same time a small fraction of projectile ions come close enough to the nucleus for large-angle scattering (KE).
- A detected backscattered particle has lost some energy during initial penetration, then lost a large fraction of its remaining energy during the large-angle scattering event, then lost more energy in leaving the solid.

Depth Scale



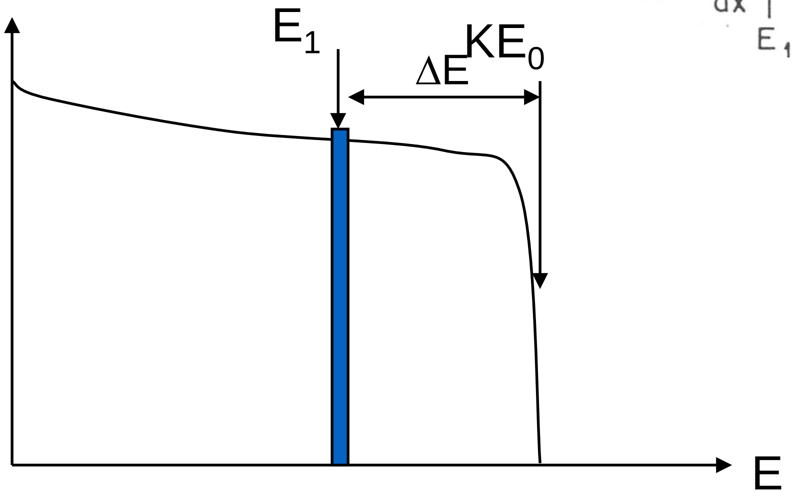
ENERGY LOSS:

$$\Delta E_{in} \simeq \frac{dE}{dx}\Big|_{E_0} \cdot t$$

$$E_t = E_0 - \Delta E_{in}$$

$$\Delta E_s = (1-K)E_t$$

$$\Delta E_{out} \simeq \frac{dE}{dx}\Big|_{E_1} \cdot \frac{t}{\cos\theta}$$



$$E_1 = K(E_0 - \Delta E_{in}) - \Delta E_{out}$$

$$E_1 = K(E_0 - \frac{dE}{dx}\Big|_{E_0} \bullet t) - (\frac{dE}{dx}\Big|_{KE_0} \bullet \frac{t}{\cos\theta})$$

Total energy loss ΔE=KE$_0$-E$_1$

$$\boxed{\Delta E = (\frac{K}{\cos\theta_1} \bullet \frac{dE}{dx}\Big|_{E_0} + \frac{1}{\cos\theta_2} \bullet \frac{dE}{dx}\Big|_{KE_0}) \bullet t = [S_o] \bullet t}$$

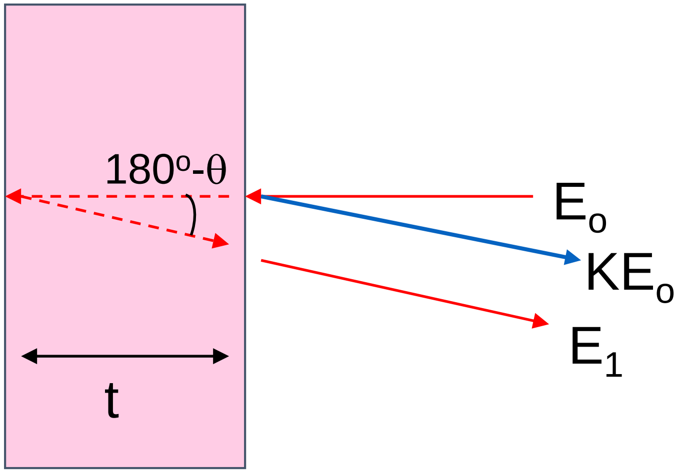
[S$_o$] is the effective stopping power

Stopping cross-section

$$\varepsilon = \frac{1}{N}\frac{dE}{dx} : \frac{\mathrm{eV}}{\mathrm{cm}}\frac{\mathrm{cm}^3}{\mathrm{atom}} = \frac{\mathrm{eVcm}^2}{\mathrm{atom}}$$

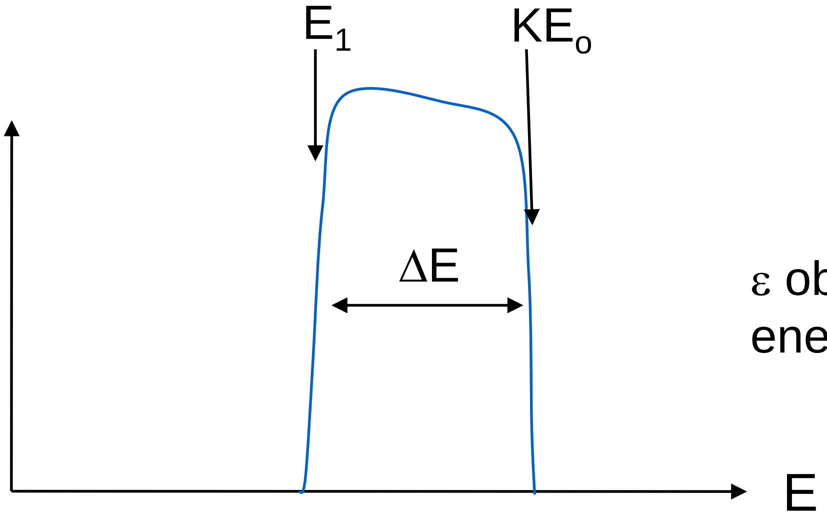
$$\Delta E = \left(\frac{K}{\cos\theta_1} \bullet N\varepsilon_{in} + \frac{1}{\cos\theta_2} \bullet N\varepsilon_{out}\right) \bullet t = N[\varepsilon_o] \bullet t$$

Depth scale: thin film



Thickness of film:

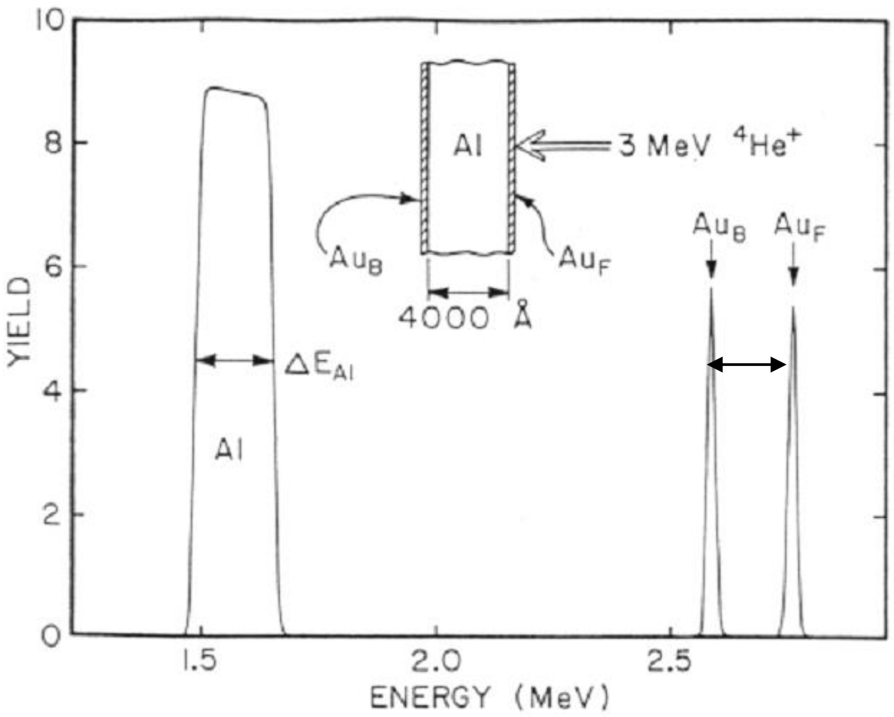
$$\Delta E = \left(K \left.\frac{dE}{dx}\right|_{E_0} + \frac{\left.\frac{dE}{dx}\right|_{KE_0}}{\cos\theta}\right)\bullet t = [S_o]\bullet t$$



$$t = \frac{\Delta E}{[S_o]} = \frac{\Delta E}{N[\varepsilon_o]}$$

ε obtained from TRIM code or empirical energy loss data fitting

Example: layer thickness



ΔE_{Al} = 165keV

ΔE_{Au} = 175keV

K_{Au} = 0.9225

K_{Al} = 0.5525

consider the Au markers

$\Delta E_{Au} = E_{AuF} - E_{AuB}$

$= [K_{Au}\, dE/dx\,|_{Eo} + 1 / (\cos 10^o) \bullet dE/dx\,|_{EAuB}] \bullet t$

$dE/dx\,|_{3MeV} = N_{Al}\, \varepsilon_{Al}\,|_{3MeV}$

$= 6.02\text{x}10^{22} \bullet 36.56\text{x}10^{-15}$

$= 2.2\text{x}10^{9}\text{eVcm}^{-1}$

$dE/dx\,|_{EAuB} = N_{Al}\, \varepsilon_{Al}\,|_{2.57MeV}$

$= 6.02\text{x}10^{22} \text{ x } 39.34\text{x}10^{-15}$

$= 2.37\text{x}10^{9} \text{ eVcm}^{-1}$

t = 3945Å

consider the Al signals

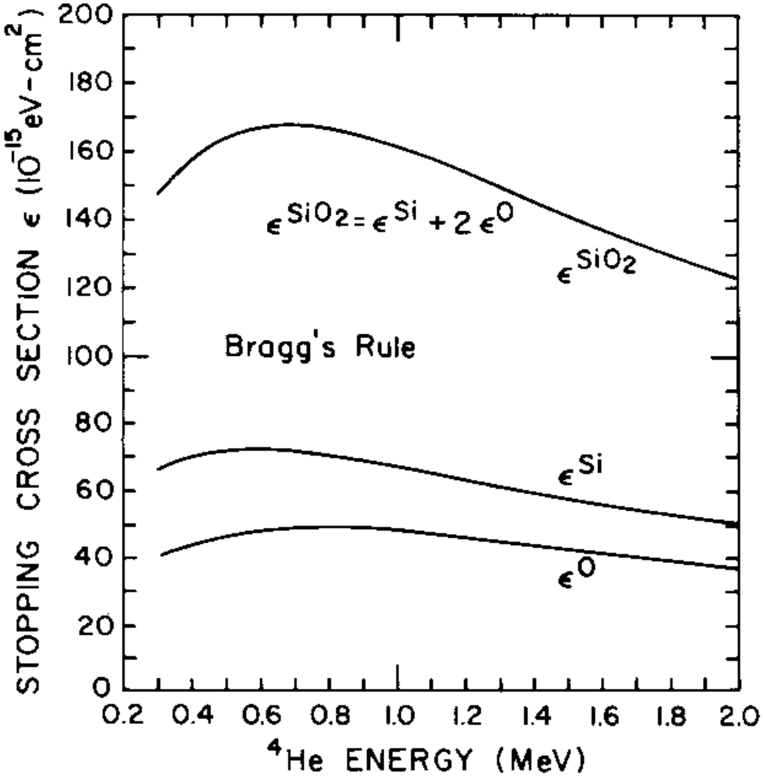
$\Delta E_{Al} = [K_{Al}\, dE/dx\,|_{Eo} + 1 / (\cos 10^o) \bullet dE/dx\,|_{KEo}] \bullet t$

t = 3937Å

Energy Loss: Bragg’s rule

For a target A_mB_n, the stopping cross-section is the sum of those of the constituent elements weighted by the abundance of the elements.

$$\varepsilon^{AmBn} = m\,\varepsilon^{A} + n\,\varepsilon^{B}$$



Example:

the stopping cross-section ε^{Al2O3} of Al_2O_3.

Given: $\varepsilon^{Al} = 44 \times 10^{-15}$eVcm^2

$\varepsilon^{O} = 35 \times 10^{-15}$eVcm^2

$\varepsilon^{Al2O3} = 2/5 \times \varepsilon^{Al} + 3/5 \times \varepsilon^{O}$

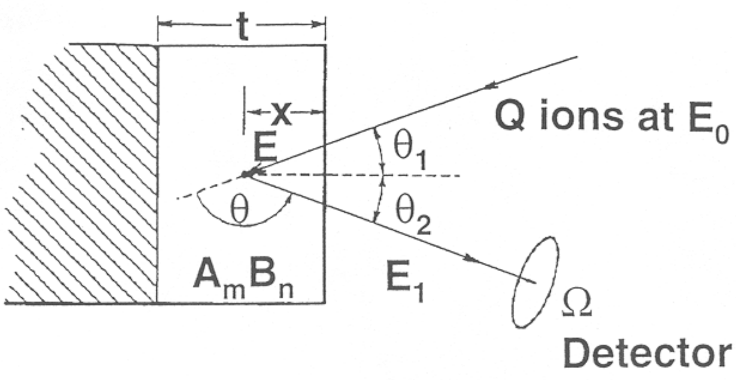
$= (2/5 \times 44 + 3/5 \times 35) \times 10^{-15}$

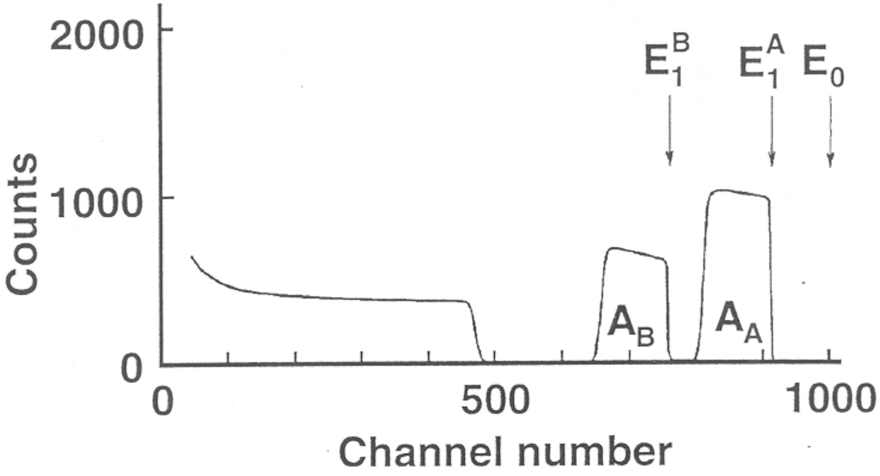
$= 38.6 \times 10^{-15}$ eV-cm^2/atom

$dE/dx(Al_2O_3)=N\varepsilon^{Al2O3}=(1.15\times10^{22})(38.6\times10^{-15})$eV/cm

=44.4 eV/Å

Quantitative analysis: composition and thickness





$$A_A = \sigma_A \bullet \Omega \bullet Q \bullet (Nt)_A$$

$$A_B = \sigma_B \bullet \Omega \bullet Q \bullet (Nt)_B$$

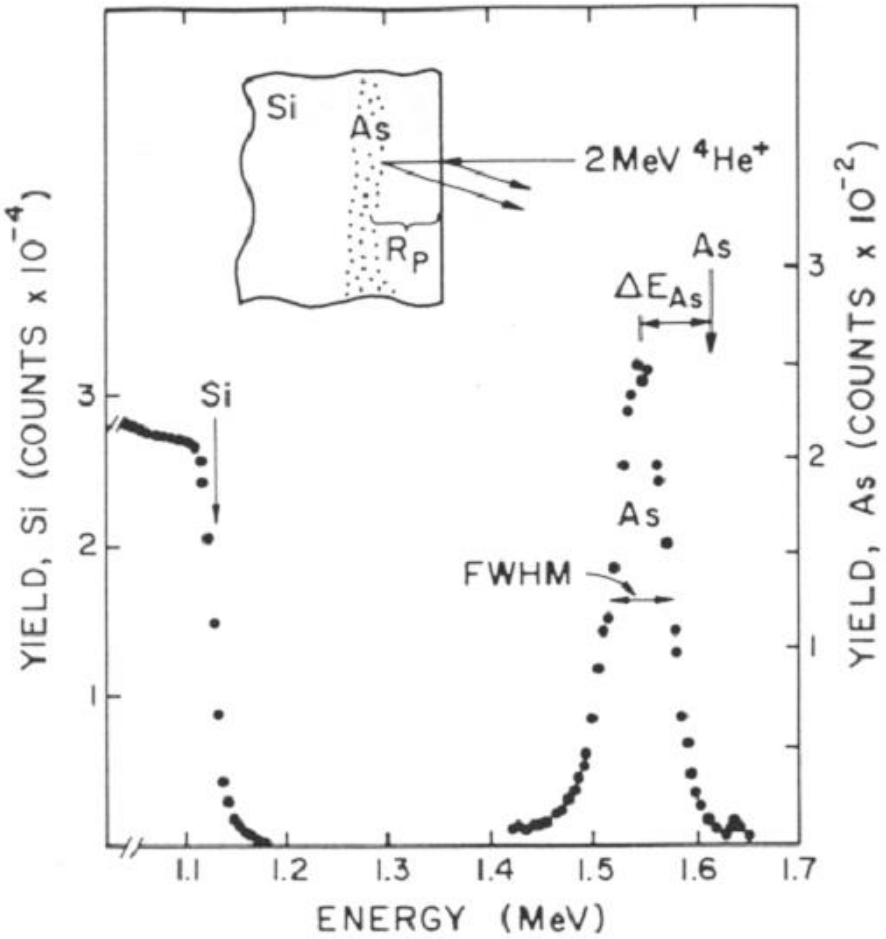
$$\frac{A_A}{A_B} = \left(\frac{\sigma_A}{\sigma_B}\right) \bullet \left(\frac{(Nt)_A}{(Nt)_B}\right) = \left(\frac{Z_A}{Z_B}\right)^2 \bullet \frac{m}{n}$$

$$\boxed{\frac{m}{n} = \left(\frac{A_A}{A_B}\right) \bullet \left(\frac{Z_B}{Z_A}\right)^2}$$

$$t = \frac{(\Delta E)_A}{[S_o]_A^{A_m B_n}} = \frac{(\Delta E)_B}{[S_o]_B^{A_m B_n}}$$

$$t = \frac{(\Delta E)_A}{N[\varepsilon_o]_A^{A_m B_n}} = \frac{(\Delta E)_B}{N[\varepsilon_o]_B^{A_m B_n}}$$

Example: As implanted Si



K_{As}=0.809; K_{Si}=0.566

$$[\varepsilon_o]_{Si}^{Si} = 92.6x10^{-15} eV - cm^2 / atom$$

$$[\varepsilon_o]_{As}^{Si} = 95.3x10^{-15} eV - cm^2 / atom$$

$$\Delta E_{As}^{Si} = 68keV$$

$$(FWHM)_{As} = 60keV$$

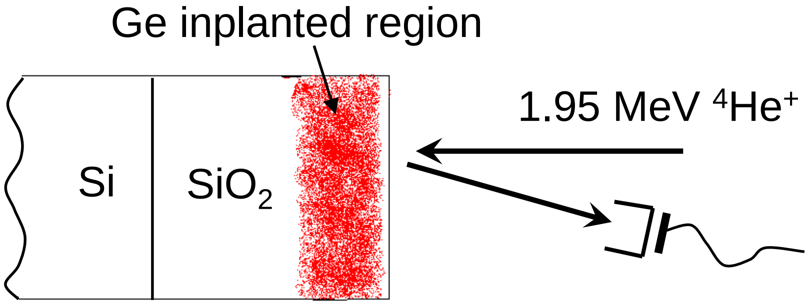
$$R_p = \frac{\Delta E_{As}^{Si}}{N[\varepsilon_o]_{As}^{Si}} = 1420\text{Å}$$

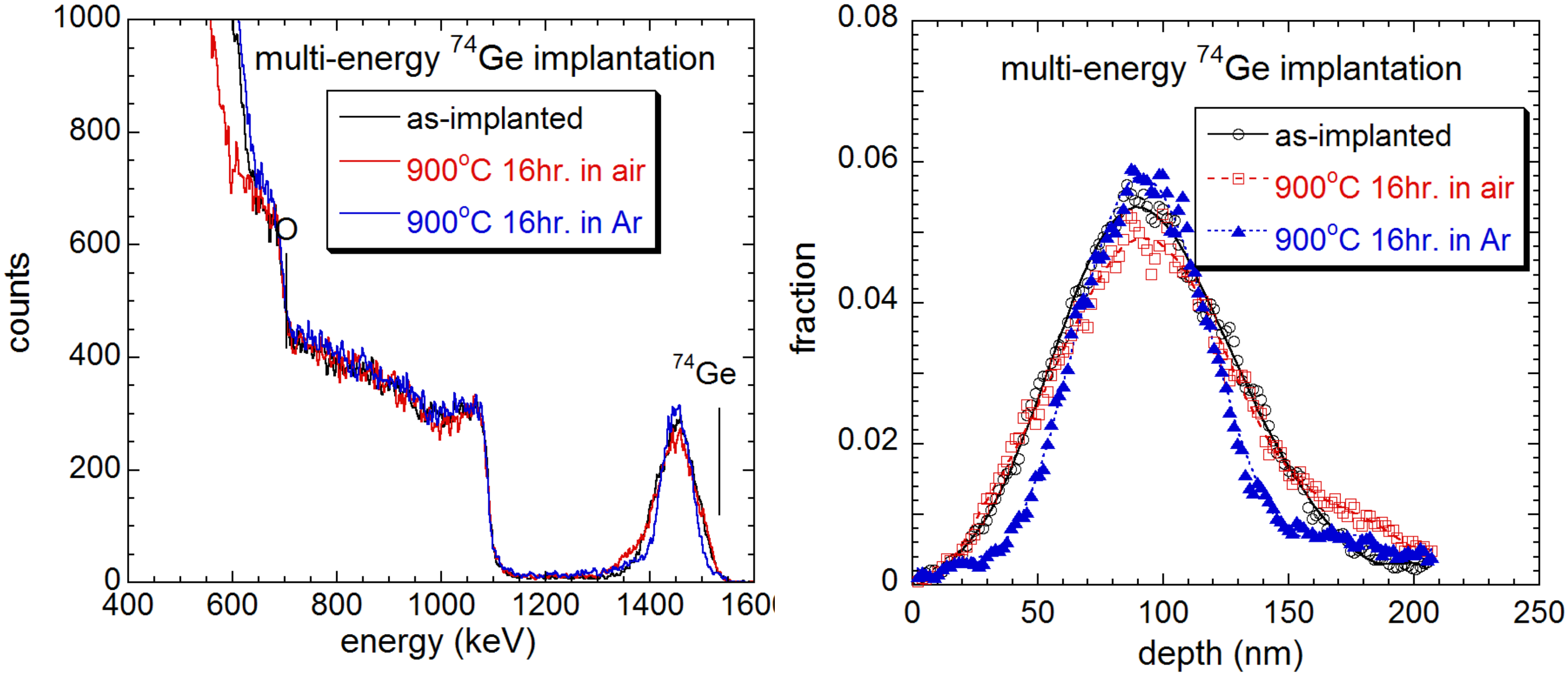
$$\Delta R_p = \frac{(FWHM)_{As}}{2.355 \bullet N[\varepsilon_o]_{As}^{Si}} = 540\text{Å}$$

Total As dose:

$$(Nt)_{As} = \frac{A_{As}}{(\sigma_{As} \bullet \Omega \bullet Q)}$$

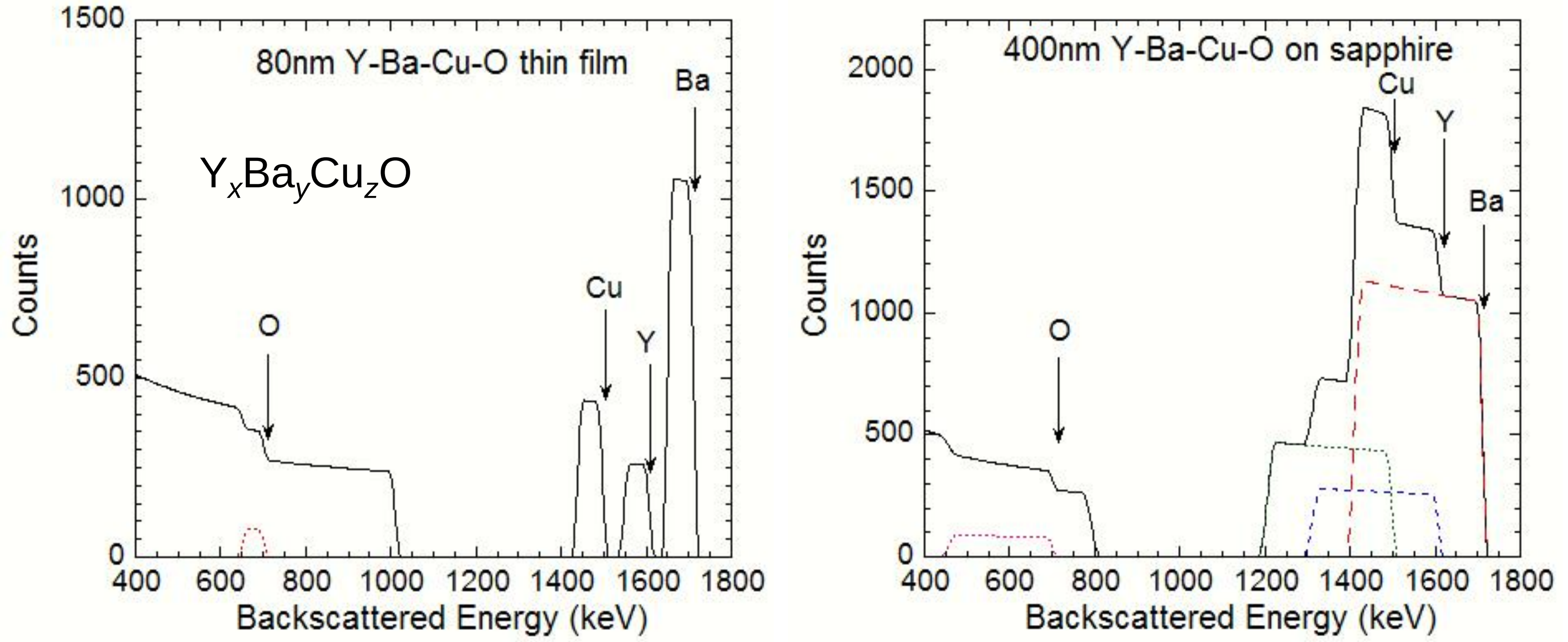
RBS Application: impurity profile





I. Sharp et al., LBNL (2004)

Thin film analysis



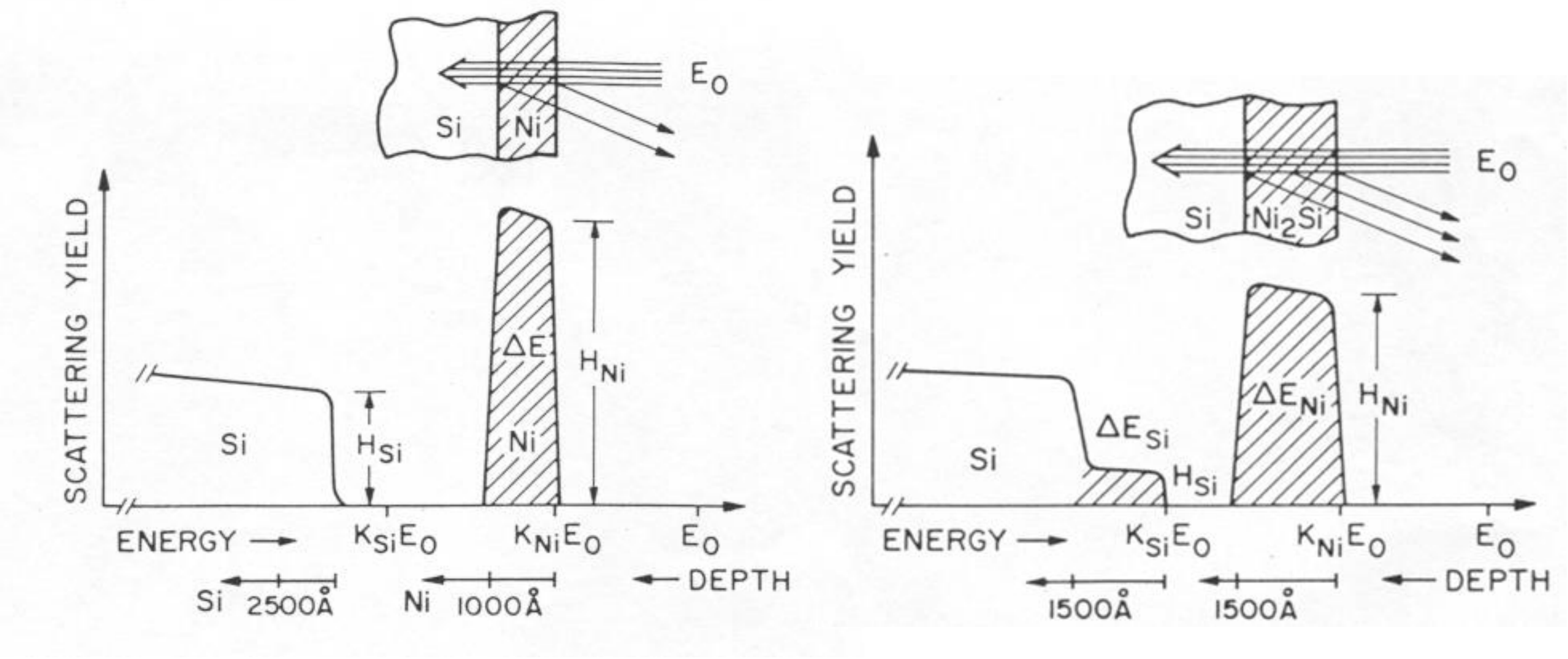
$$\frac{y}{x} = \frac{A_Y}{A_{Ba}} \bullet \left(\frac{Z_{Ba}}{Z_Y}\right)^2$$

$$\frac{y}{x} \approx \frac{H_Y}{H_{Ba}} \bullet \left(\frac{Z_{Ba}}{Z_Y}\right)^2$$

Example: silicide formation (1970-80s)

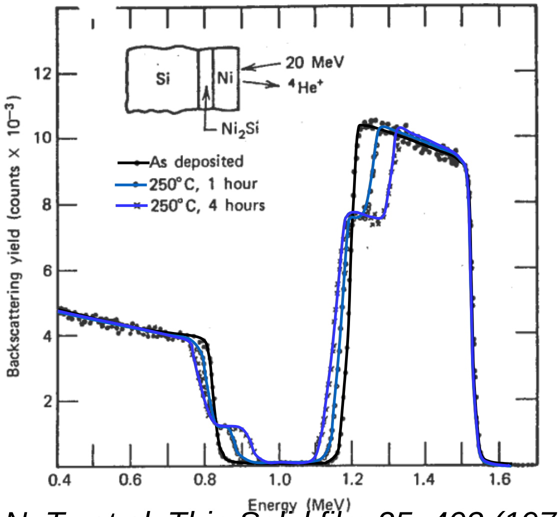
Before reaction

After reaction

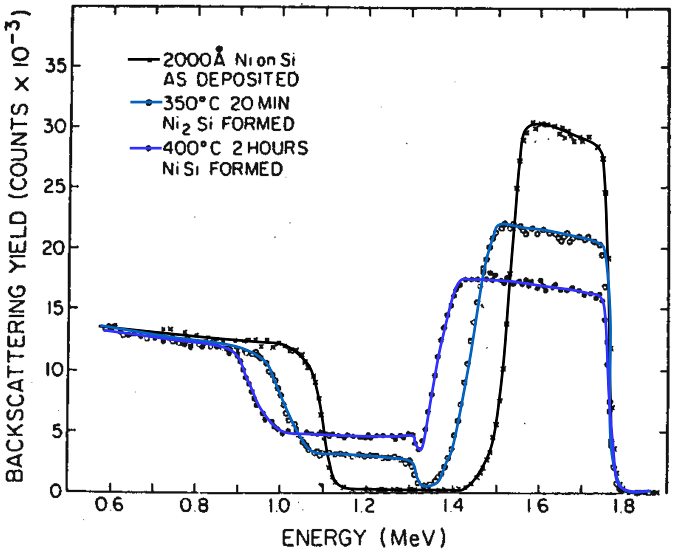


Wei-Kan Chu, James W. Mayer and Marc-A. Nicolet, Backscattering Spectrometry, (Academic Press, New York 1978).

RBS application: silicide formation

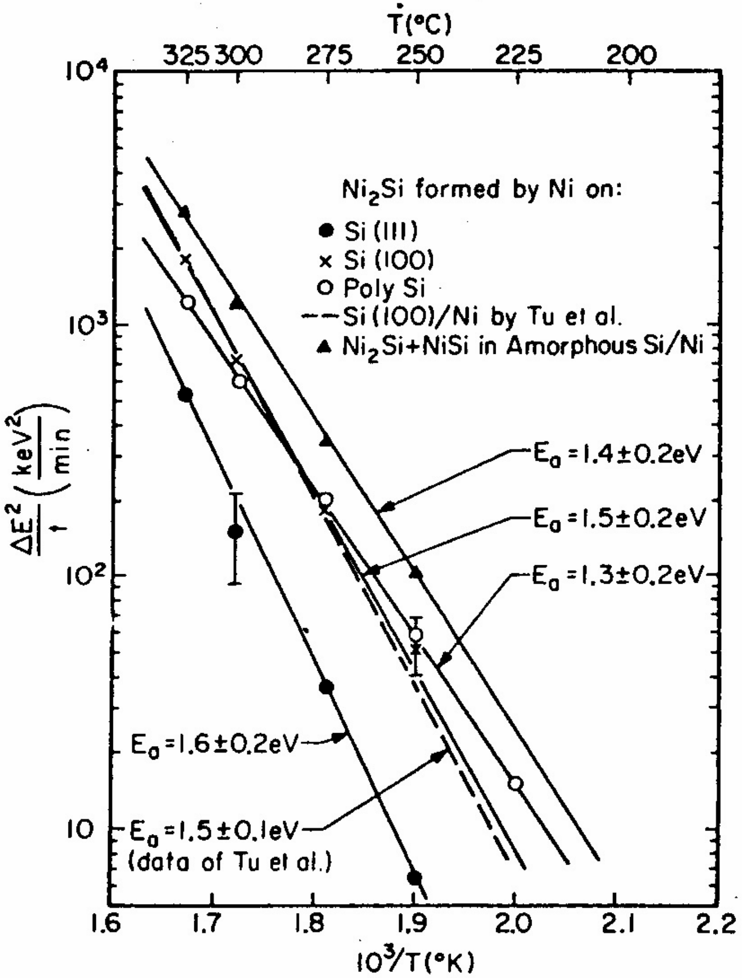


K. N. Tu et al. Thin Solid film 25, 403 (1975).



K. N. Tu et al. Japn, J. Appl. Phys. Suppl. 2 Pt 1 669 (1974).

Reaction kinetics:

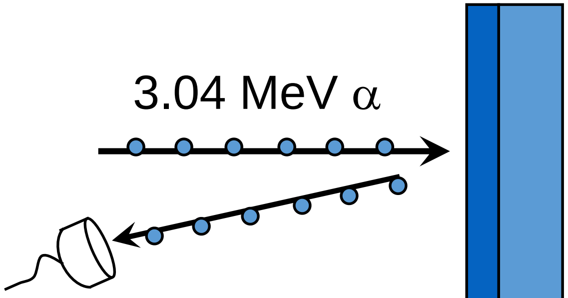


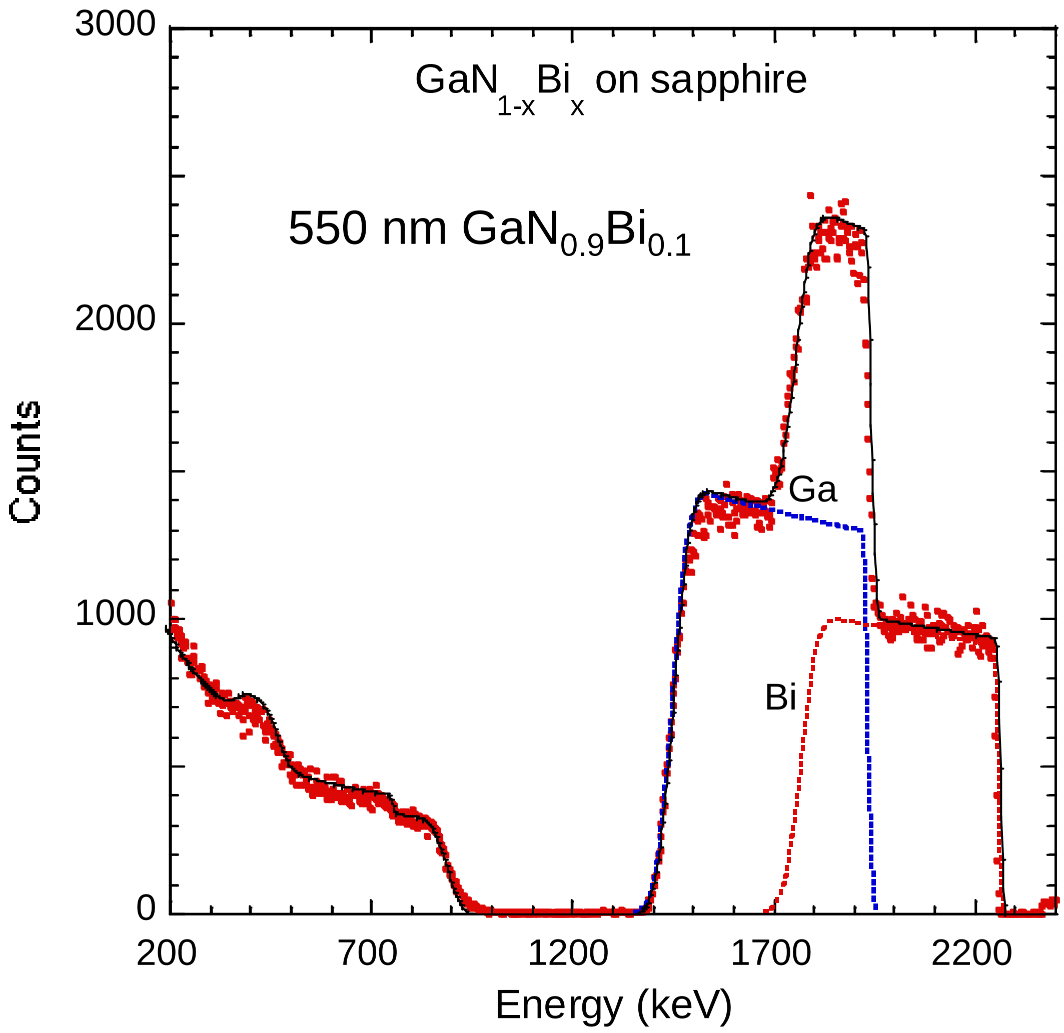
J. O. Olowolafe et al. Thin Solid film 38, 143 (1976).

IBA Data Analysis

- Starts with a simple guess sample structure (film thickness and composition)
- Simulates spectrum and directly compare to experimental data
- Iterates simulated structure to fit experimental data (either automatically or manually)
- An ideal software:
  - able to handle different data files
  - have large data base for various ion-solid interaction: resonant scattering, nuclear reaction, etc.
  - User friendly interface
  - Fast simulation
  - Can simulate sample non-uniformity (roughness, compositional gradient, etc.)
  - Able to correct for electronic errors (pile up, dead time, charge up, etc)

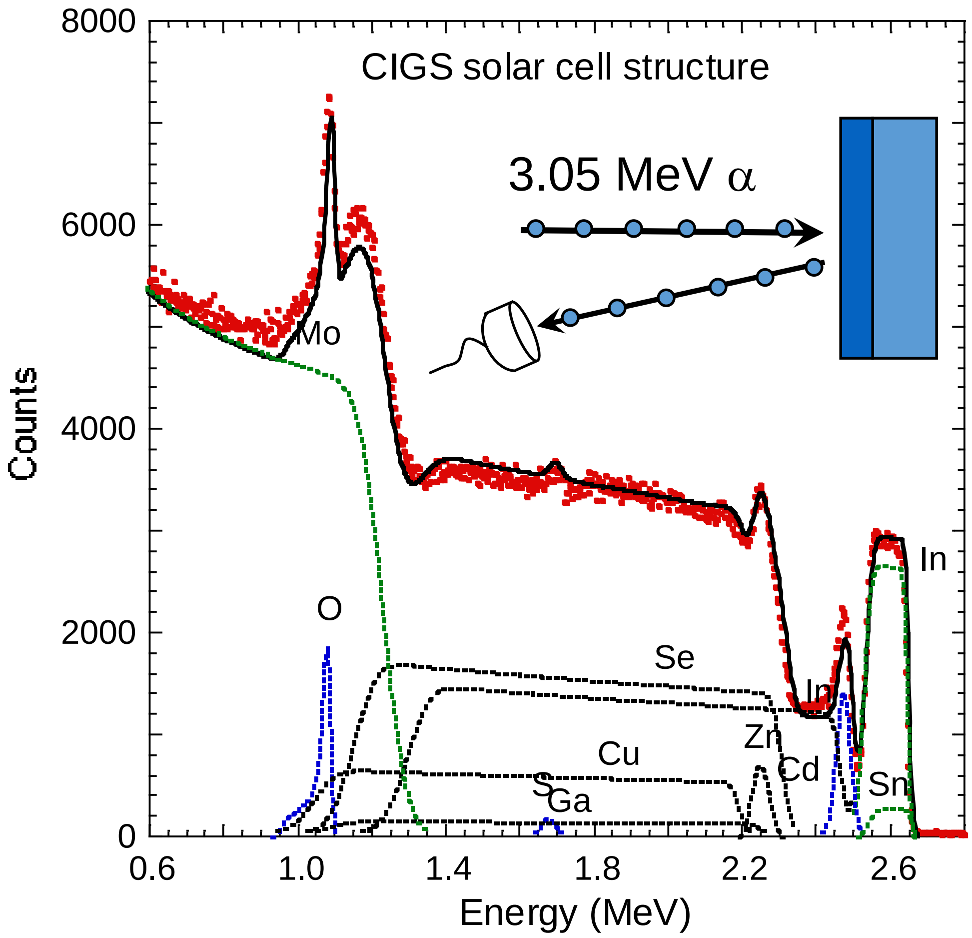
Thin Film Analysis: single layer





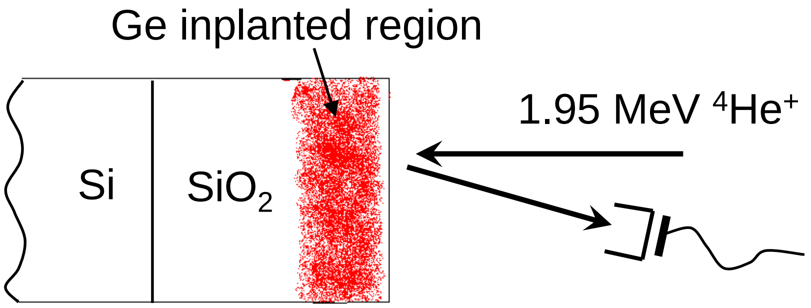
A.X. Levendar, LBNL

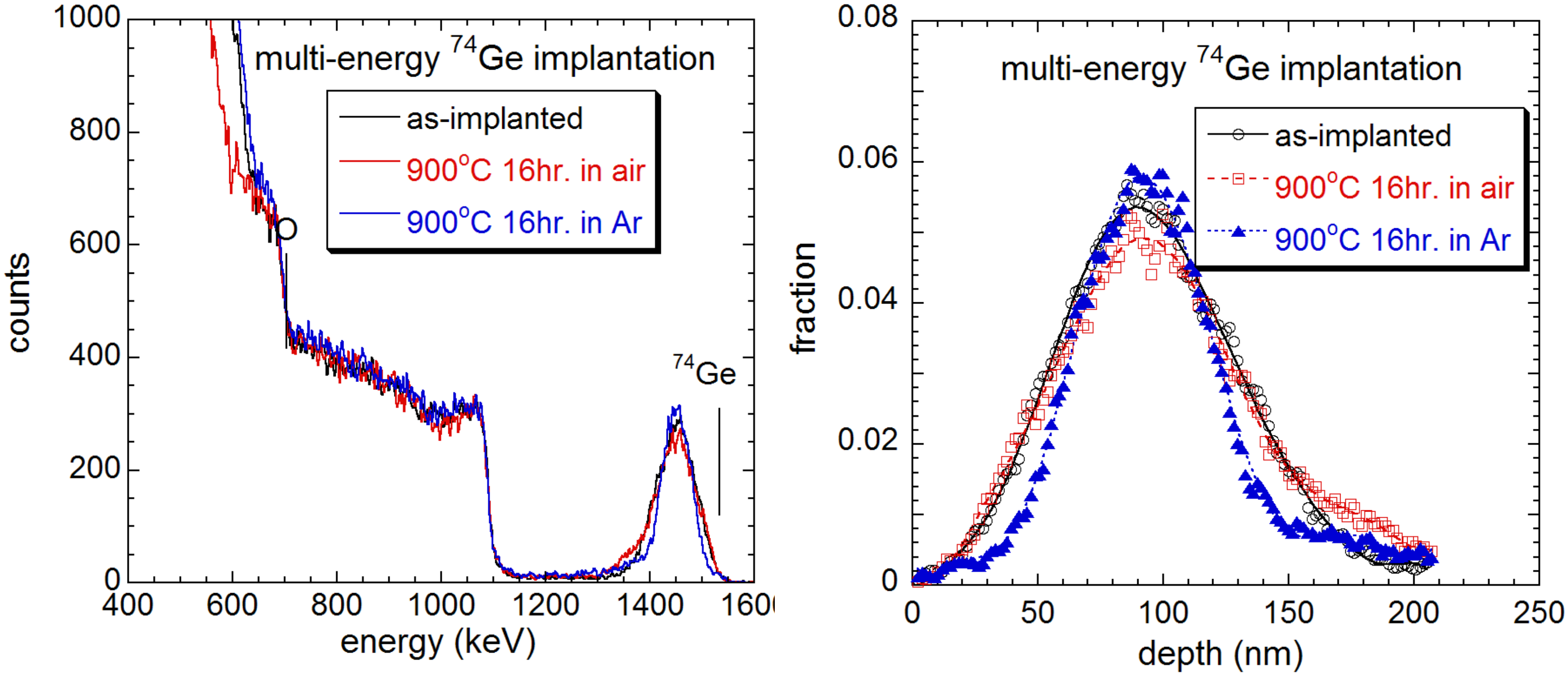
Thin film analysis: multilayers




ITO
150 nm ITO
35 nm ZnO
i-ZnO
45 nm CdS
CdS
2 μm $CuGa_{0.16}In_{0.84}Se_2$
CIGS
Mo
glass

Impurity profile





I. Sharp et al., LBNL (2004)

Strengths of RBS

- Simple in principle
- Fast and direct
- Quantitative without standard
- Depth profiling without chemical or physical sectioning
- Non-destructive
- Wide range of elemental coverage
- No special specimen preparation required
- Can be applied to crystalline or amorphous materials
- Simultaneous analysis with various ion beam techniques (PIXE, PIGE, channeling, etc.)

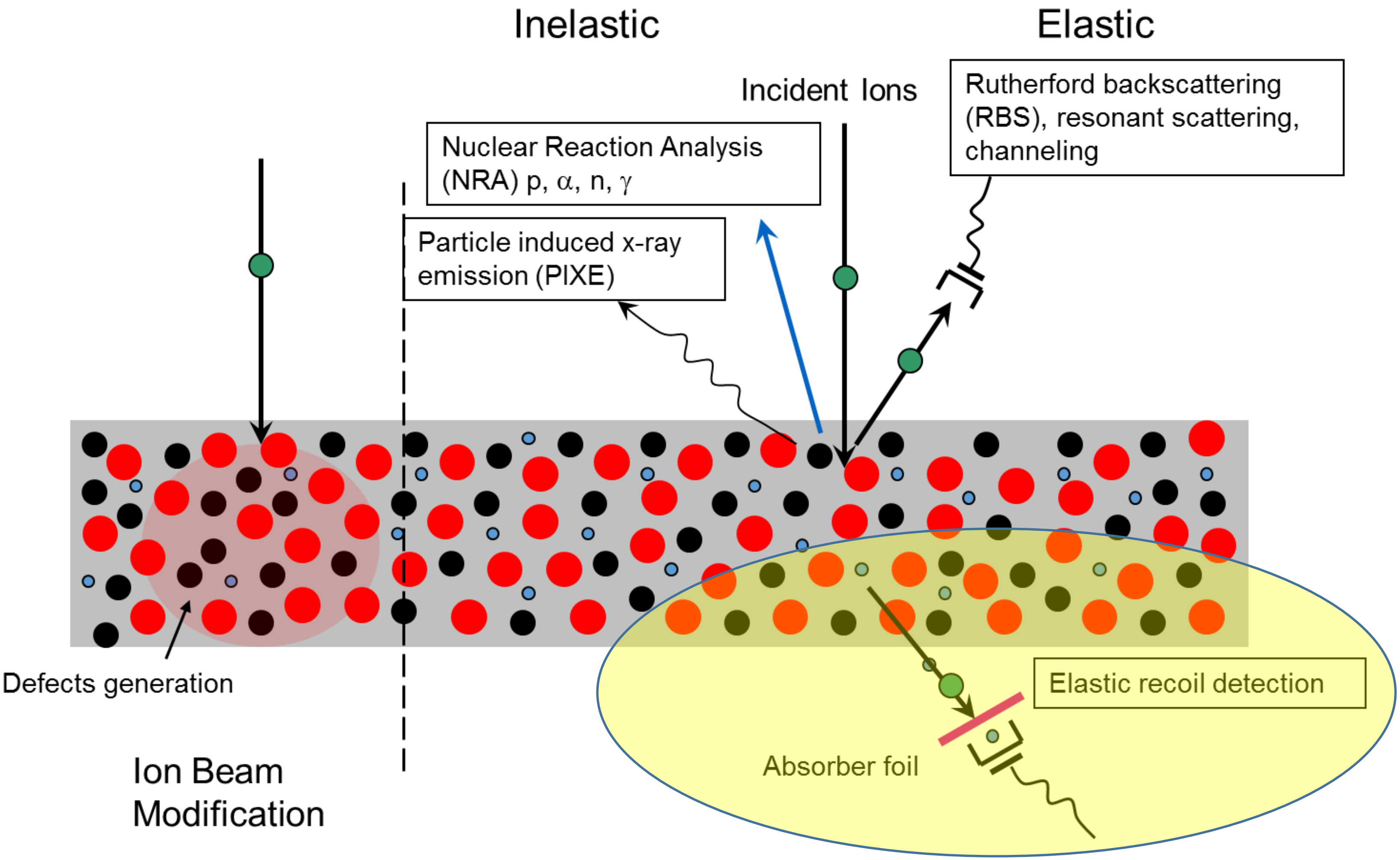
Weaknesses of RBS

- Poor lateral resolution (~0.5-1mm)
- Moderate depth resolution (>50Å)
- No microstructural information
- No phase identification
- Poor mass resolution for target mass heavier than 70amu (PIXE)
- Detection of light impurities more difficult (e.g. Li, B, C, O, etc) (non-Rutherford scattering, Nuclear Reaction Analysis)
- Data may not be obvious: require knowledge of the technique (simulation software)

Hydrogen Forward Scattering (HFS) (Elastic Recoil Detection Analsyis ERDA)

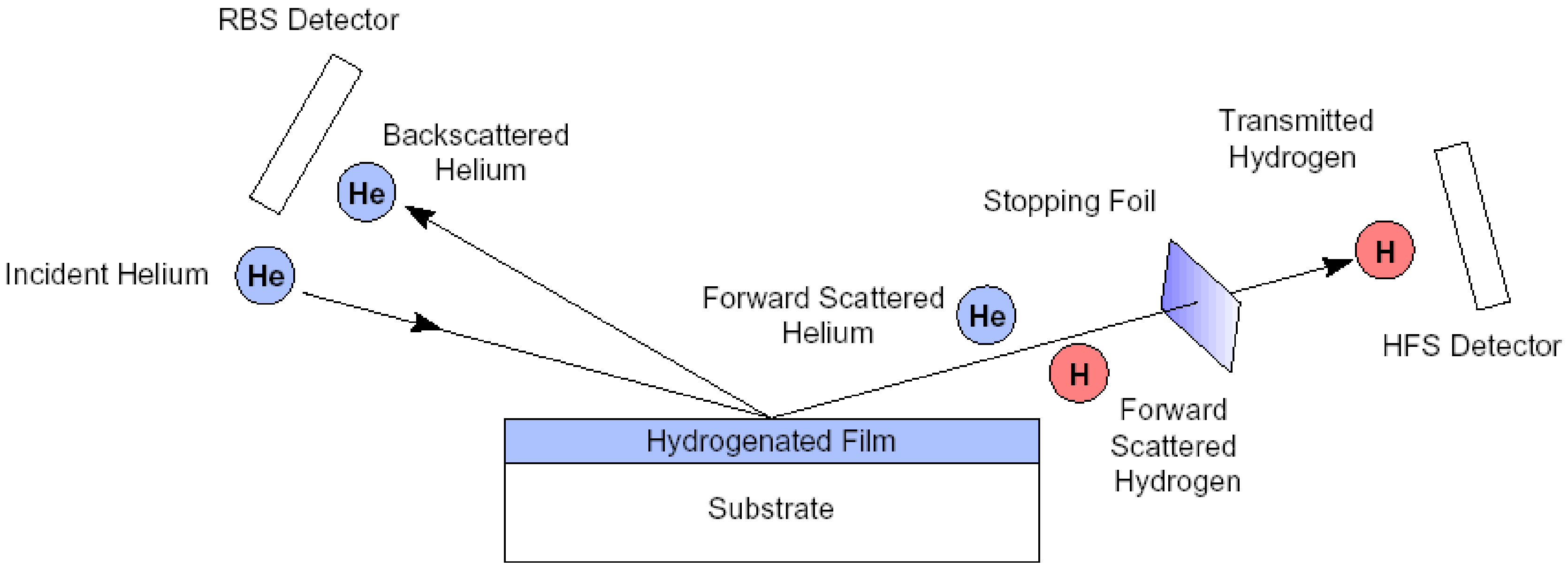
Hydrogen Forward Scattering (HFS)

Generally known as elastic recoil detection analysis (ERDA)



Hydrogen Forward Scattering (HFS)

Generally known as Elastic Recoil Detection (ERD)

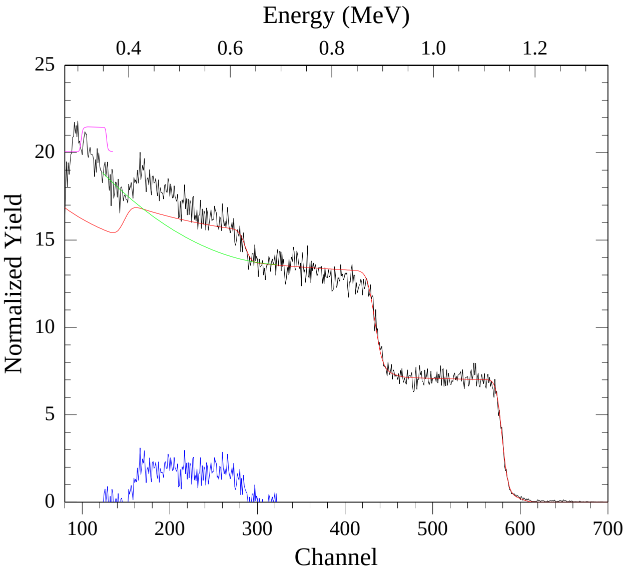


Charles Evans and Assoc., RBS APPLICATION SERIES NO. 3

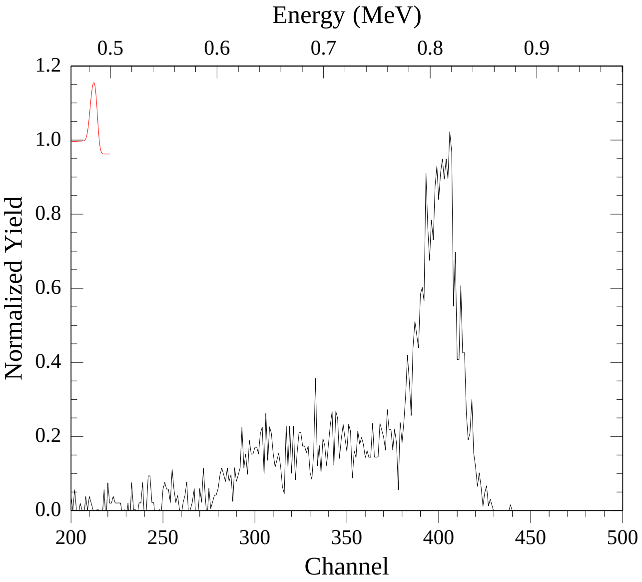
- Quantitative hydrogen and deuterium profiling
- Good sensitivity (~0.01at% of H)
- Can be perform simultaneously with RBS and PIXE
- Profiling with any light element in solid (using heavy ion beam, ERD)

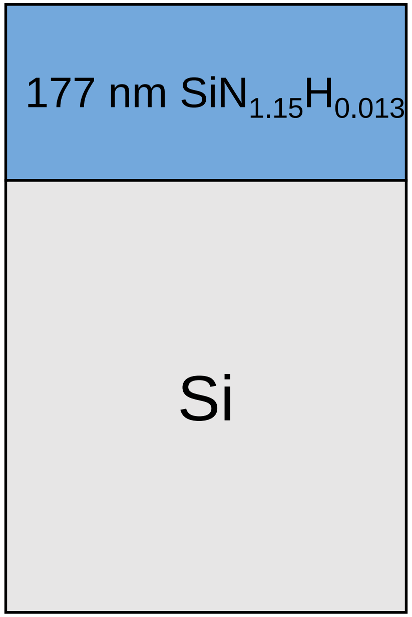
HFS: a-SiN:H film

RBS



HFS





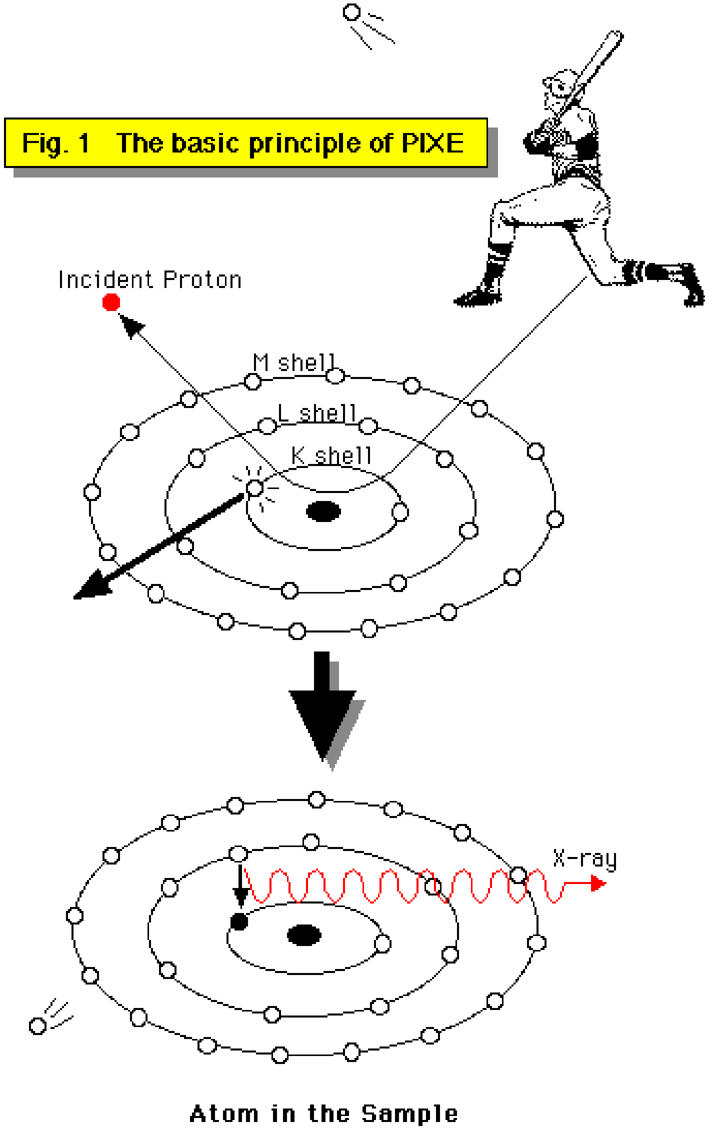
177 nm $SiN_{1.15}H_{0.013}$

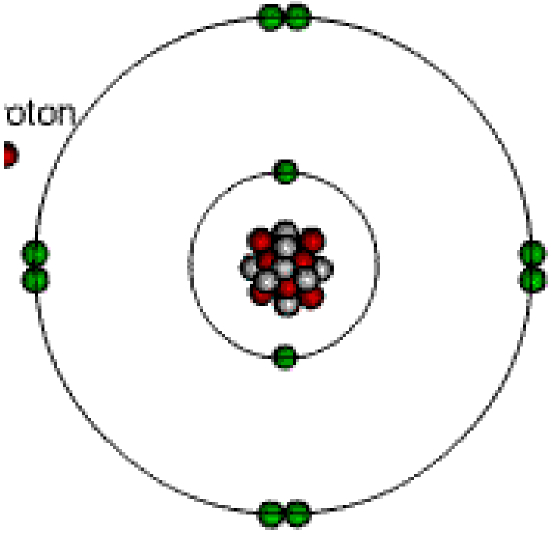
Si

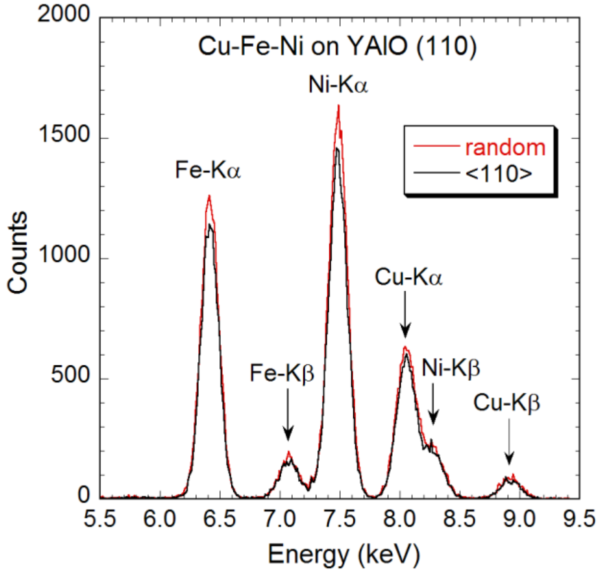
Courtesy: F. Hellman group, 2008

Particle Induced X-ray Emission (PIXE)

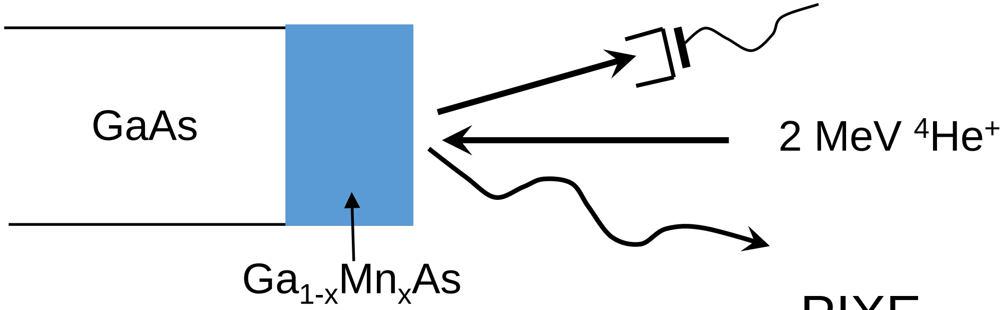
Fig. 1 The basic principle of PIXE



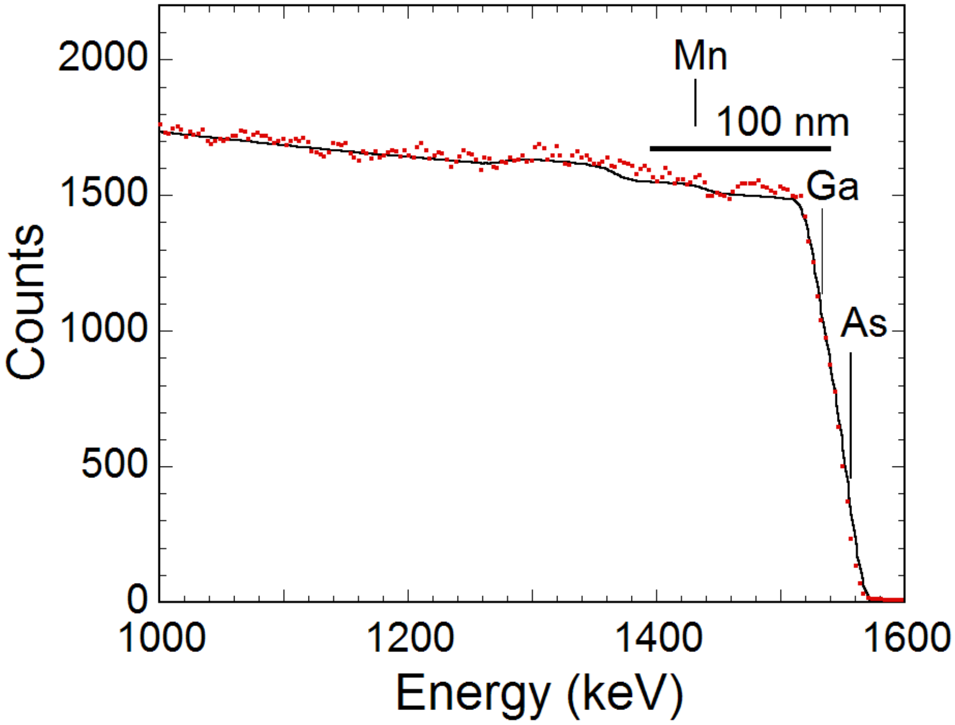




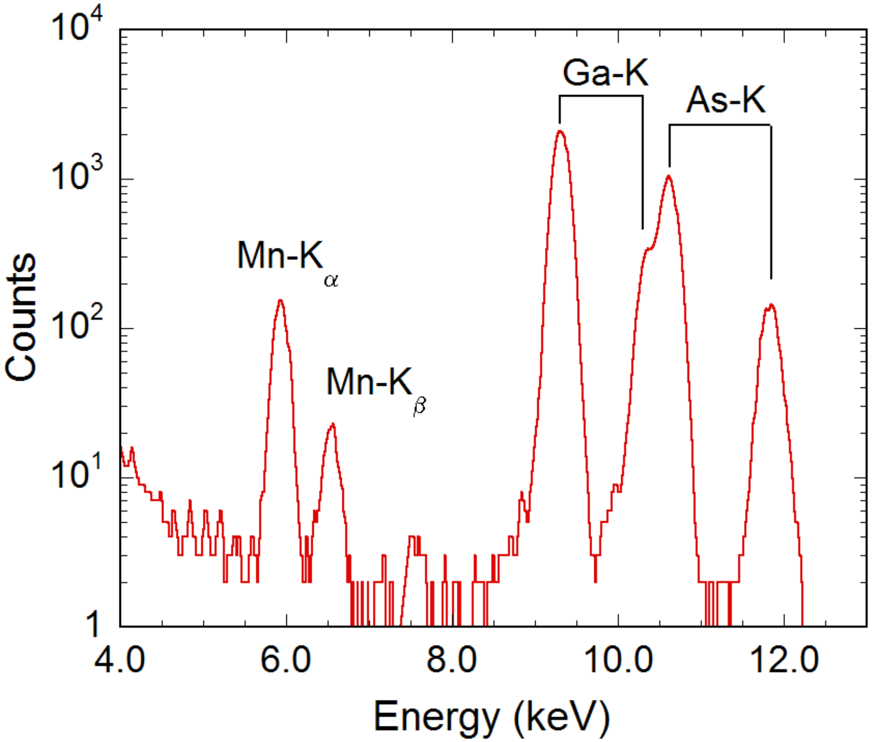
PIXE: Light impurity in heavy matrix



RBS



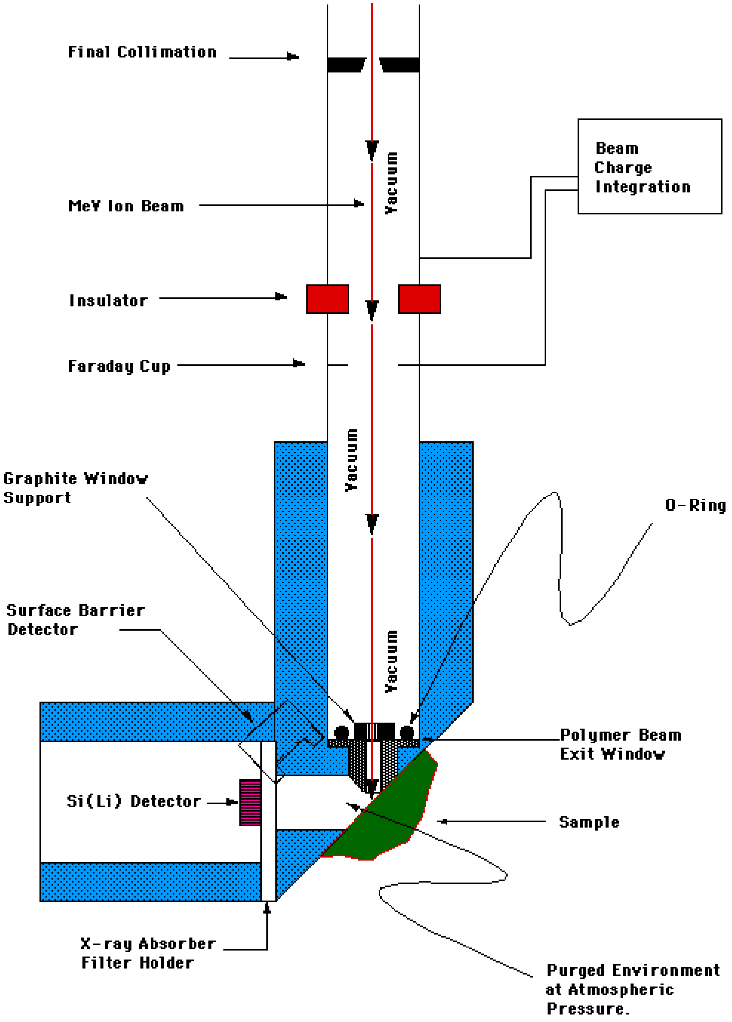
PIXE



K. M. Yu et al. 2002.

PIXE Application: Geology, Art, Archeology, Biology

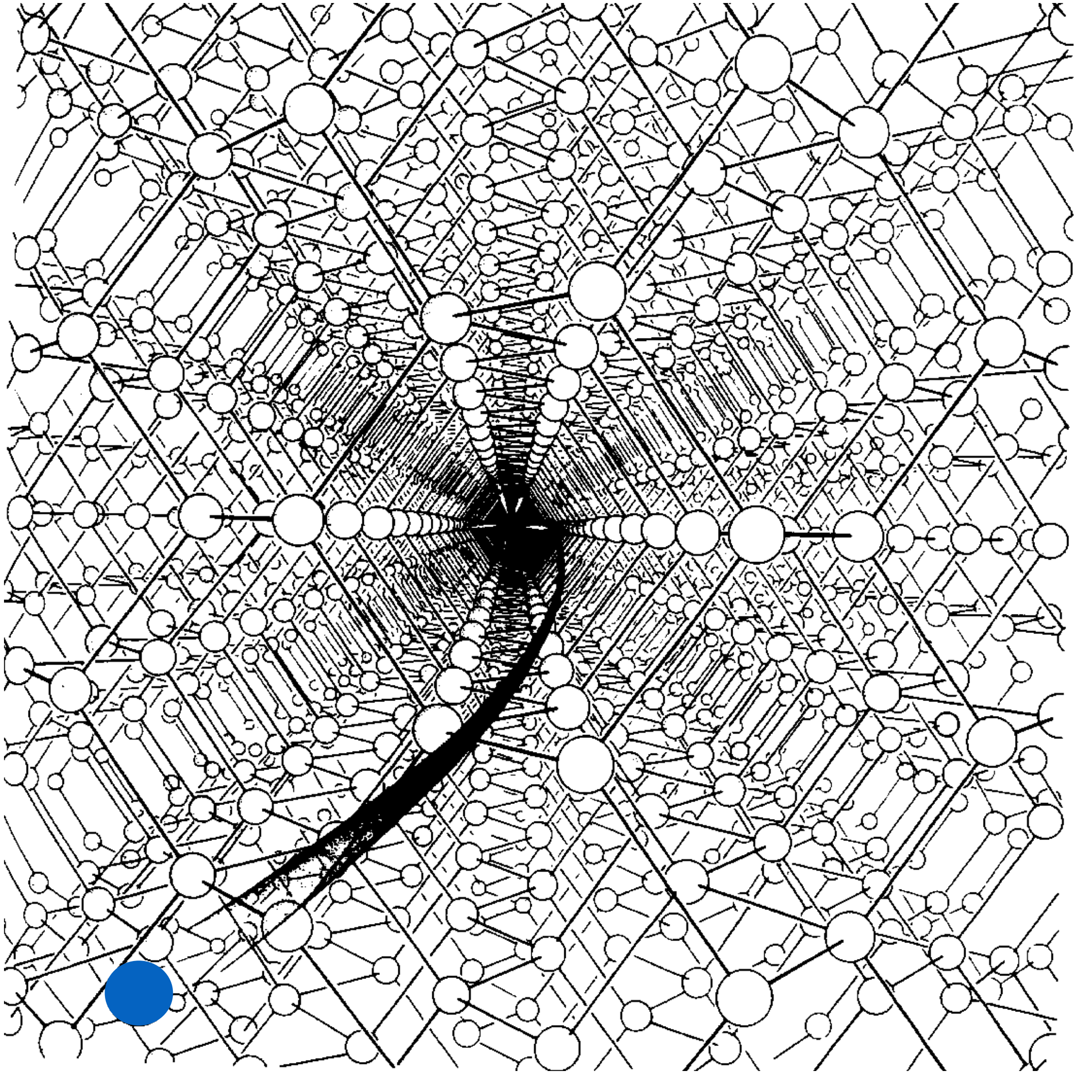
External Beam



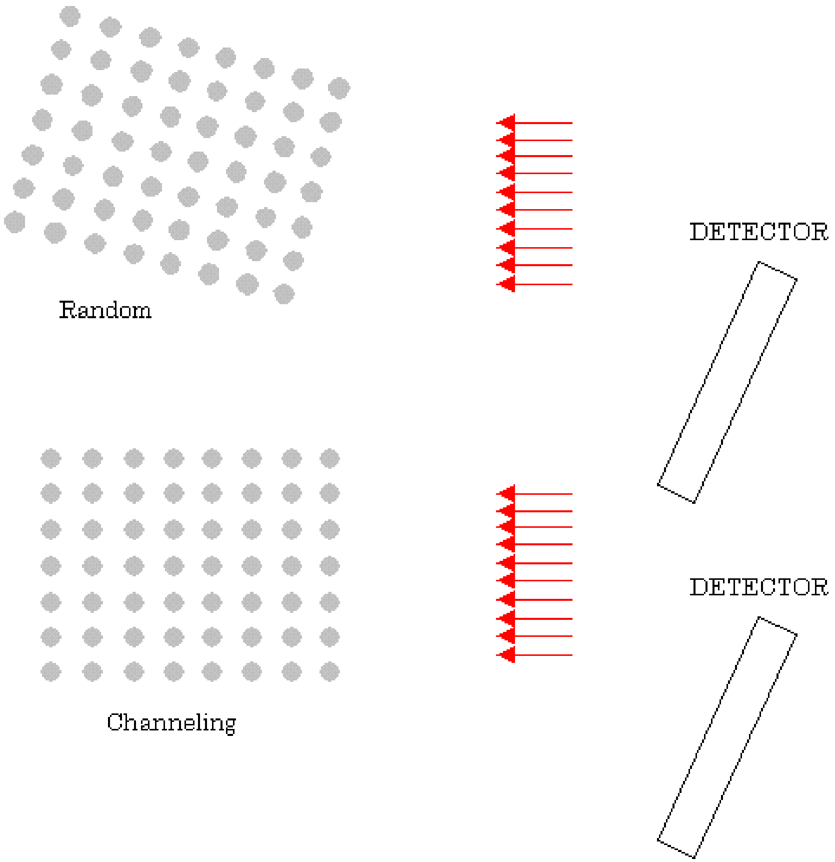
HARVARD PIXE SYSTEM

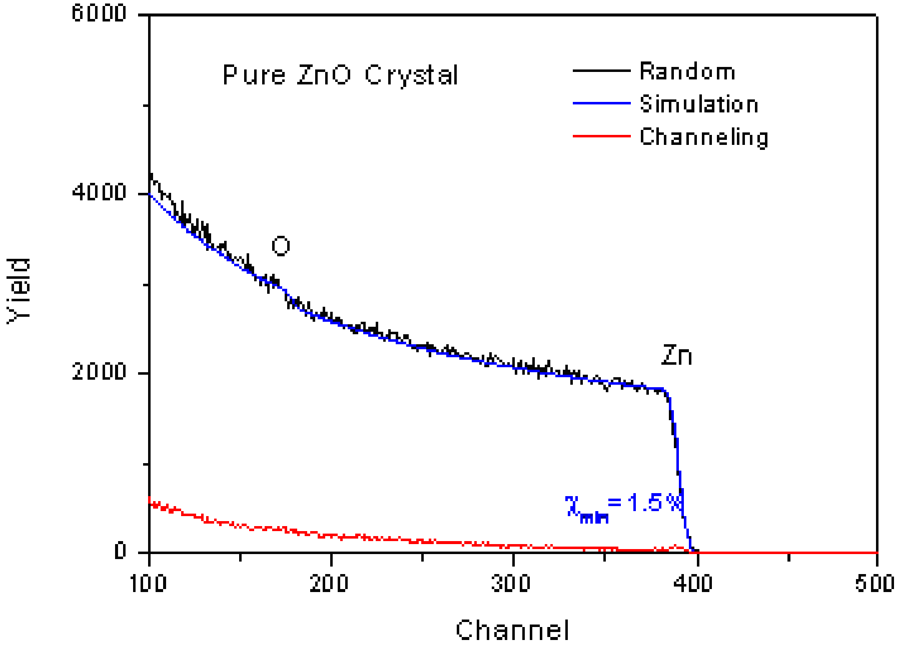
Figure 1. External PIXE set-up at IOP.

Ion channeling



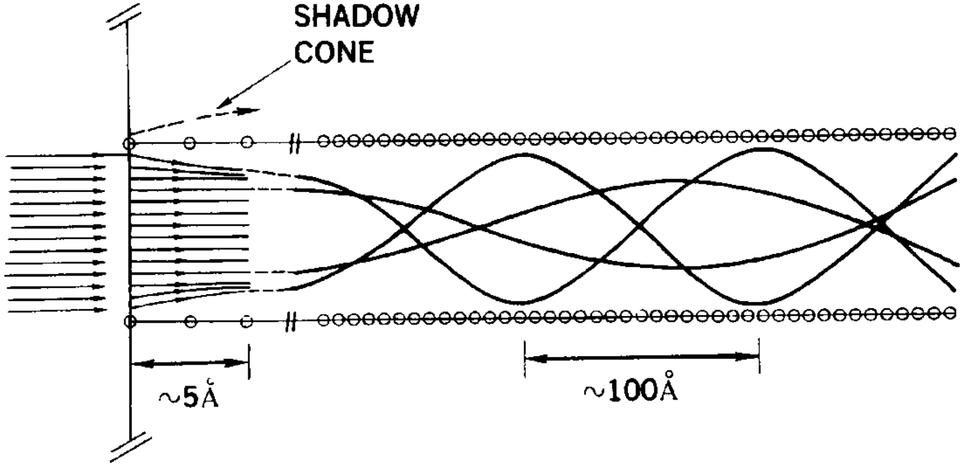
Ion Channeling

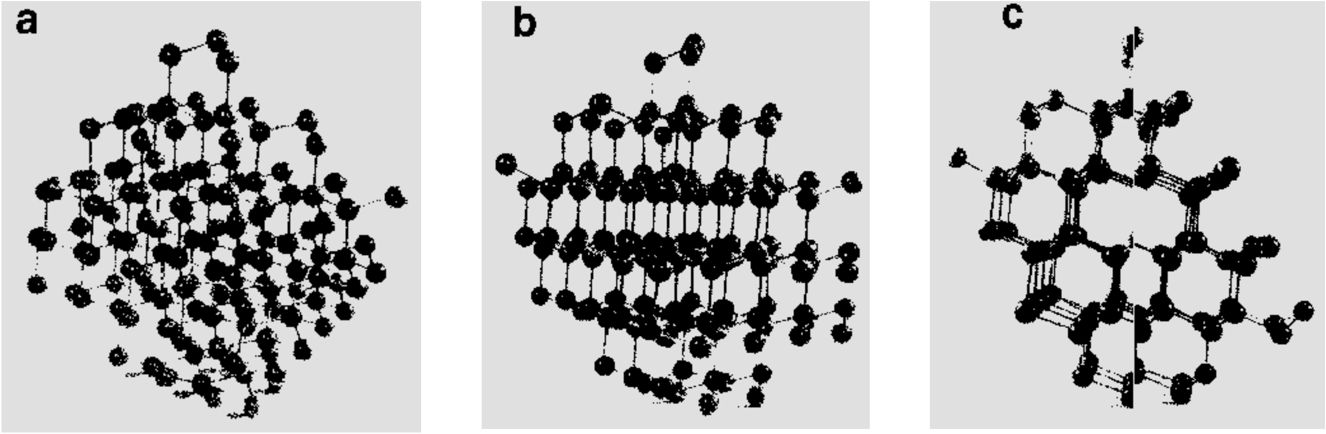




Kobelco Steel Group

Ion Channeling



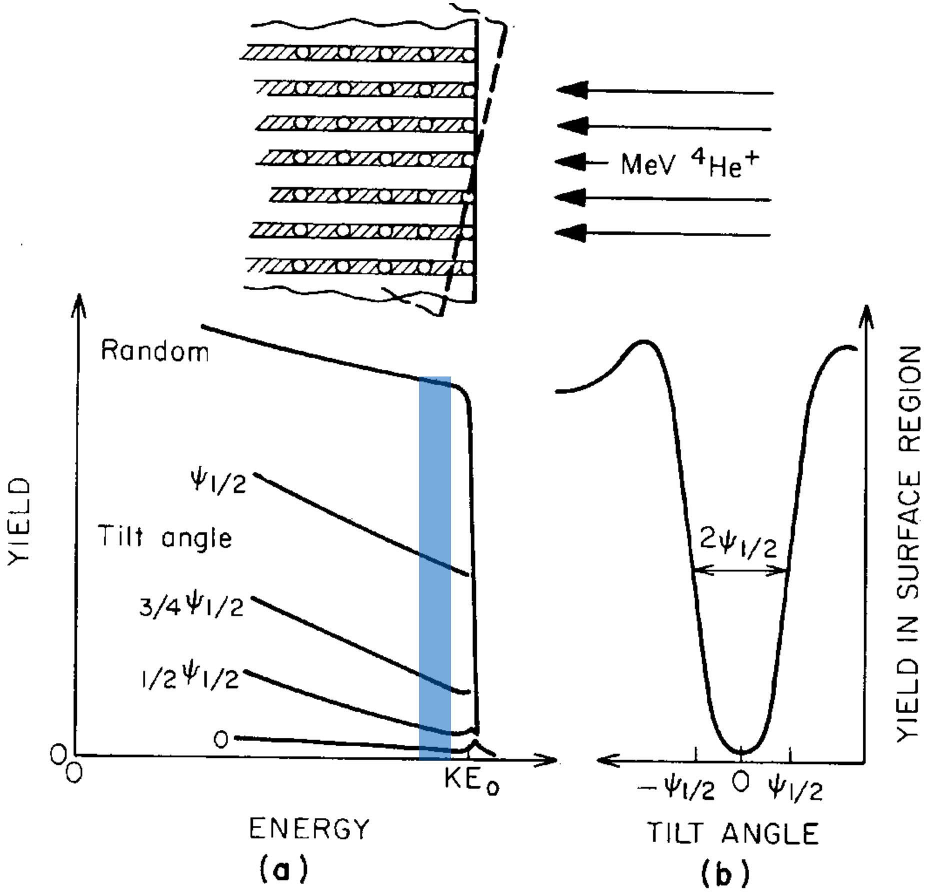


random

Planar channel

Axial channel

Ion Channeling:
minimum yield and critical angle



Two important parameters to characterize channeling results:

1. Minimum yield:

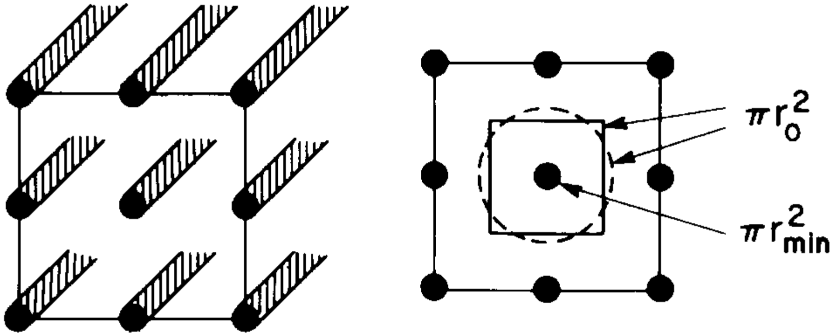
$$\chi_{\min} = \frac{Y_{channeled}}{Y_{random}}$$

~0.02-0.06

2. Critical half-angle, $\psi_{1/2}$ indicates presence of defects responsible for beam dechanneling

Ion Channeling:
minimum yield and critical angle

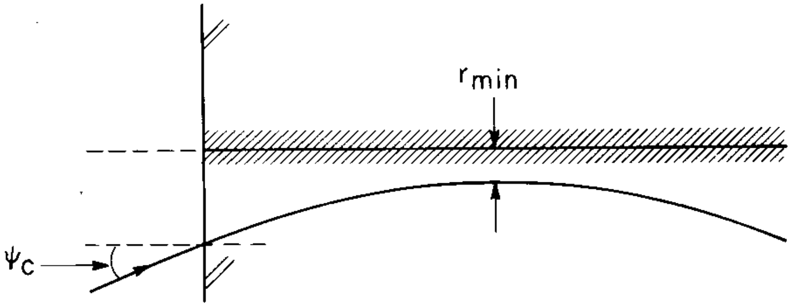
Minimum Yield, χ_{min}



$$\chi_{\min} = \frac{Y_{channeled}}{Y_{random}}$$

$$\chi_{\min} \approx \frac{\pi r_{\min}^2}{\pi r_o^2} \sim 0.02 - 0.05$$

Critical half-angle, $\psi_{1/2}$

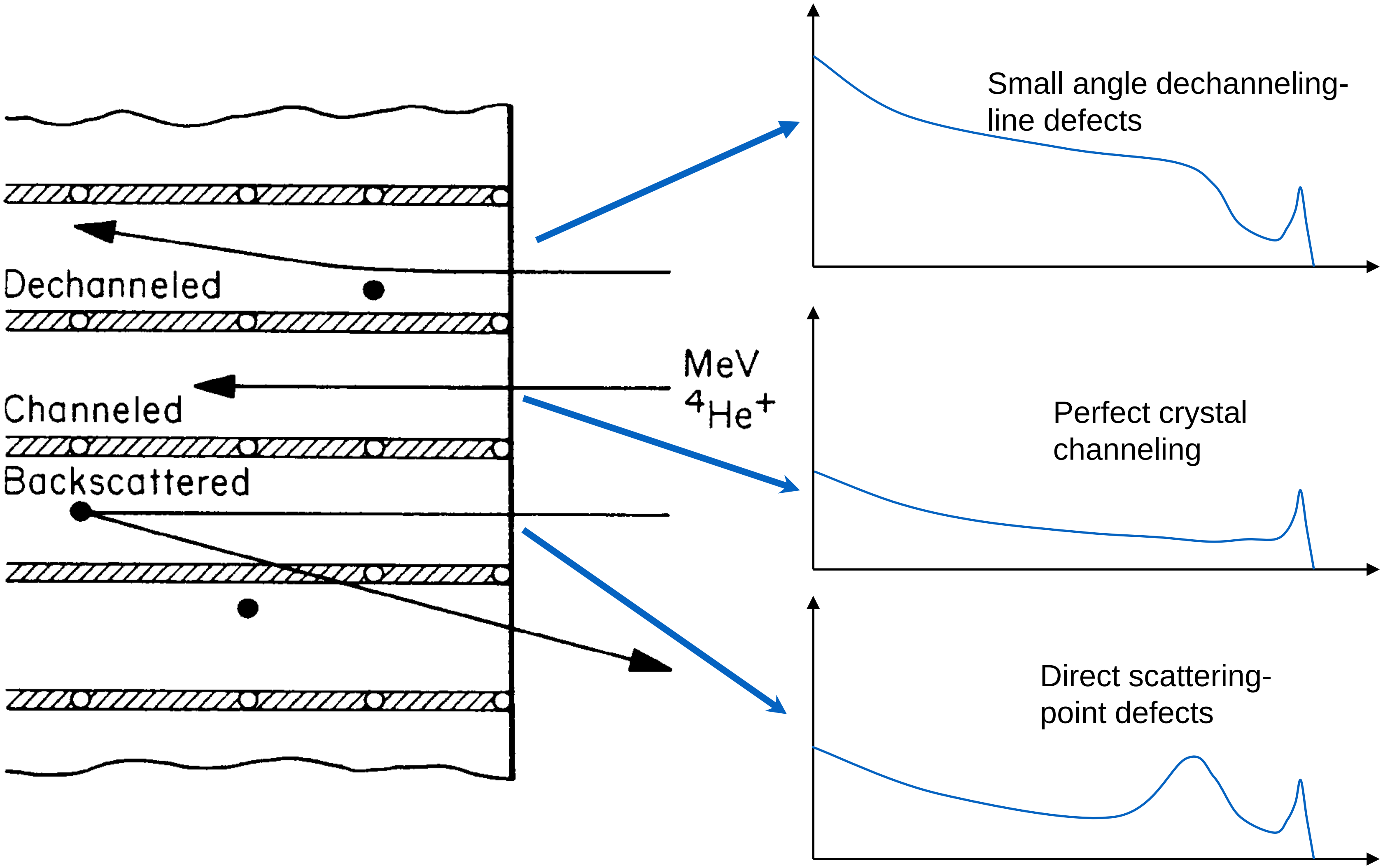


$$\Psi c = \frac{1}{\sqrt{2}} \left(\frac{2Z_1Z_2e^2}{Ed}\right)^{1/2} \left\{ \ln\left[\left(\frac{Ca}{\rho}\right)^2 + 1\right] \right\}^{1/2}$$

where d is the distance of atoms in a row, a is the Thomas-Fermi screeing distance, r is rms thermal vibration

$$\Psi_{1/2} \sim \Psi_c \sim \left(\frac{2Z_1Z_2}{E}\right)^2 \sim 0.5 - 1^o$$

Dechanneling by defects

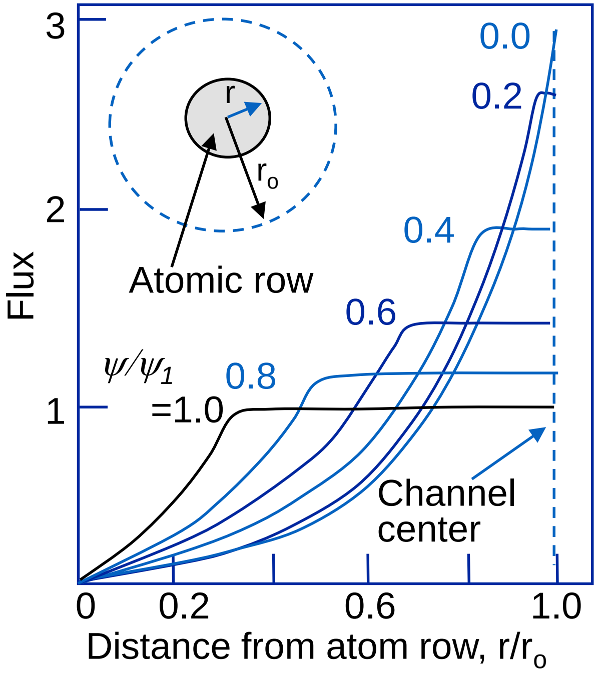


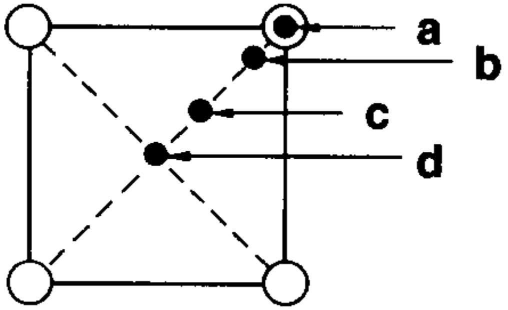
Small angle dechanneling- line defects

Perfect crystal channeling

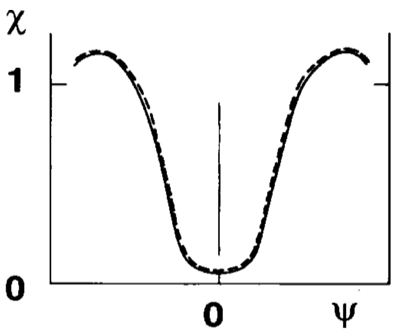
Direct scattering- point defects

Channeling: Impurity Lattice Location

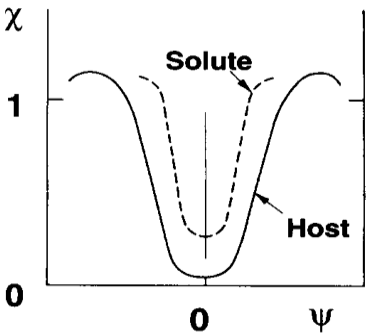




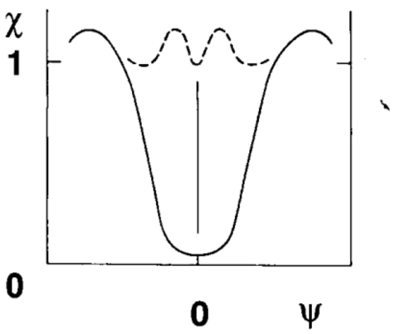
Channel cross section



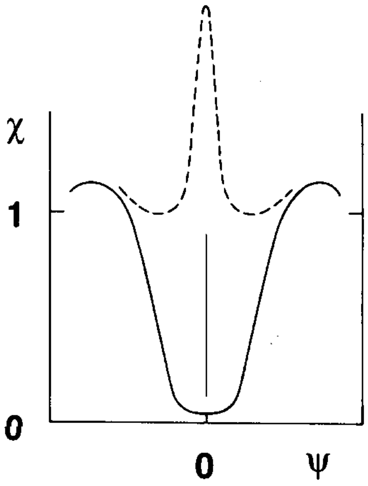
a. Substitutional



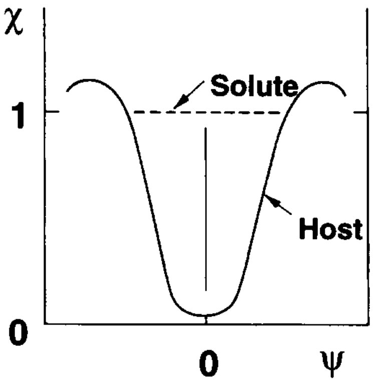
b. Small displacement



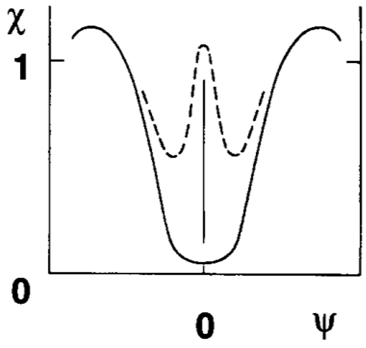
c. Large displacement



d. Center of channel (interstitial)



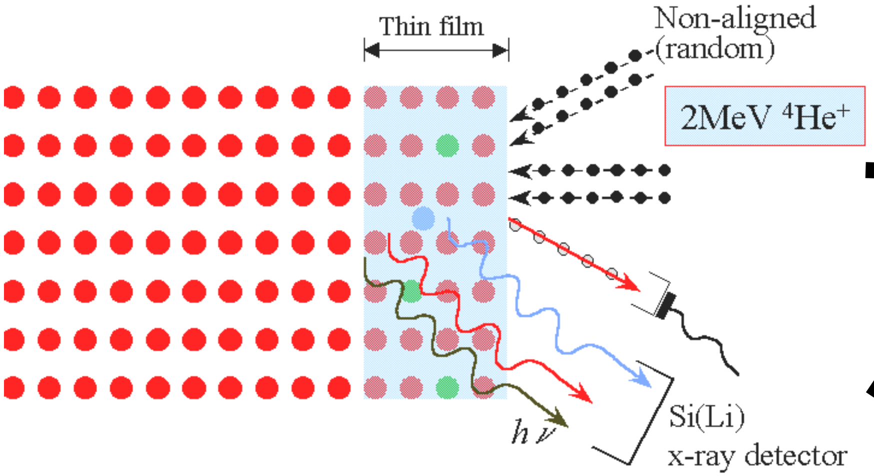
e. Random

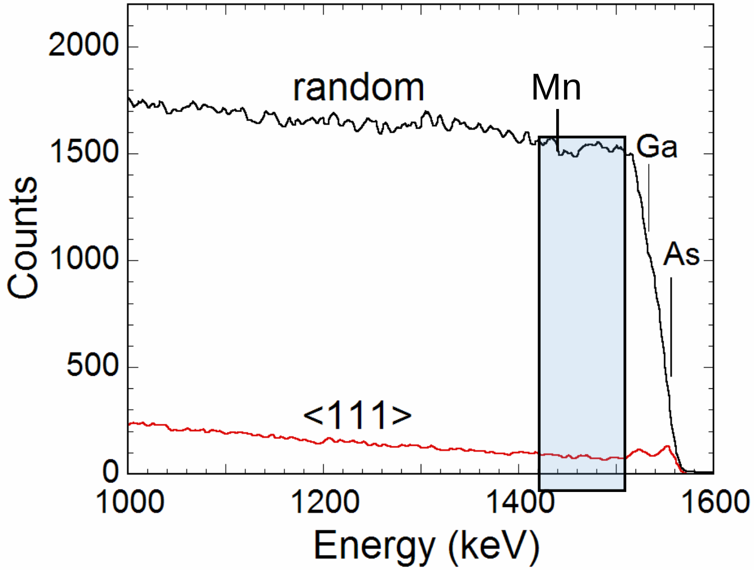


f. Substitutional plus interstitial

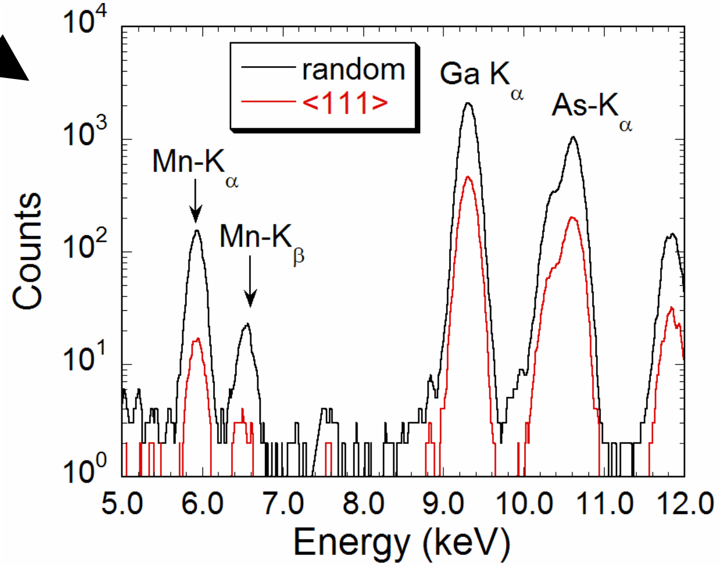
Experimental techniques : combined channeling RBS/PIXE

Rutherford backscattering (RBS)





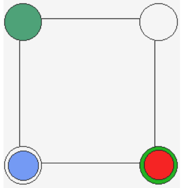
Particle-induced x-ray emission (PIXE)



c-RBS: crystalline quality of film (from GaAs backscattering yields)

c-PIXE: substitutionality of Mn atoms w.r.t. host GaAs

Channeling: $Ga_{1-x-y}Be_yMn_xAs$



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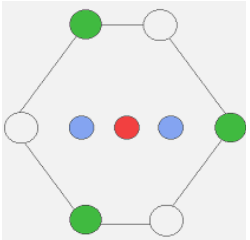

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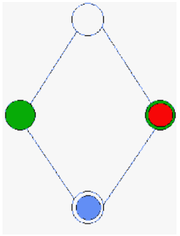
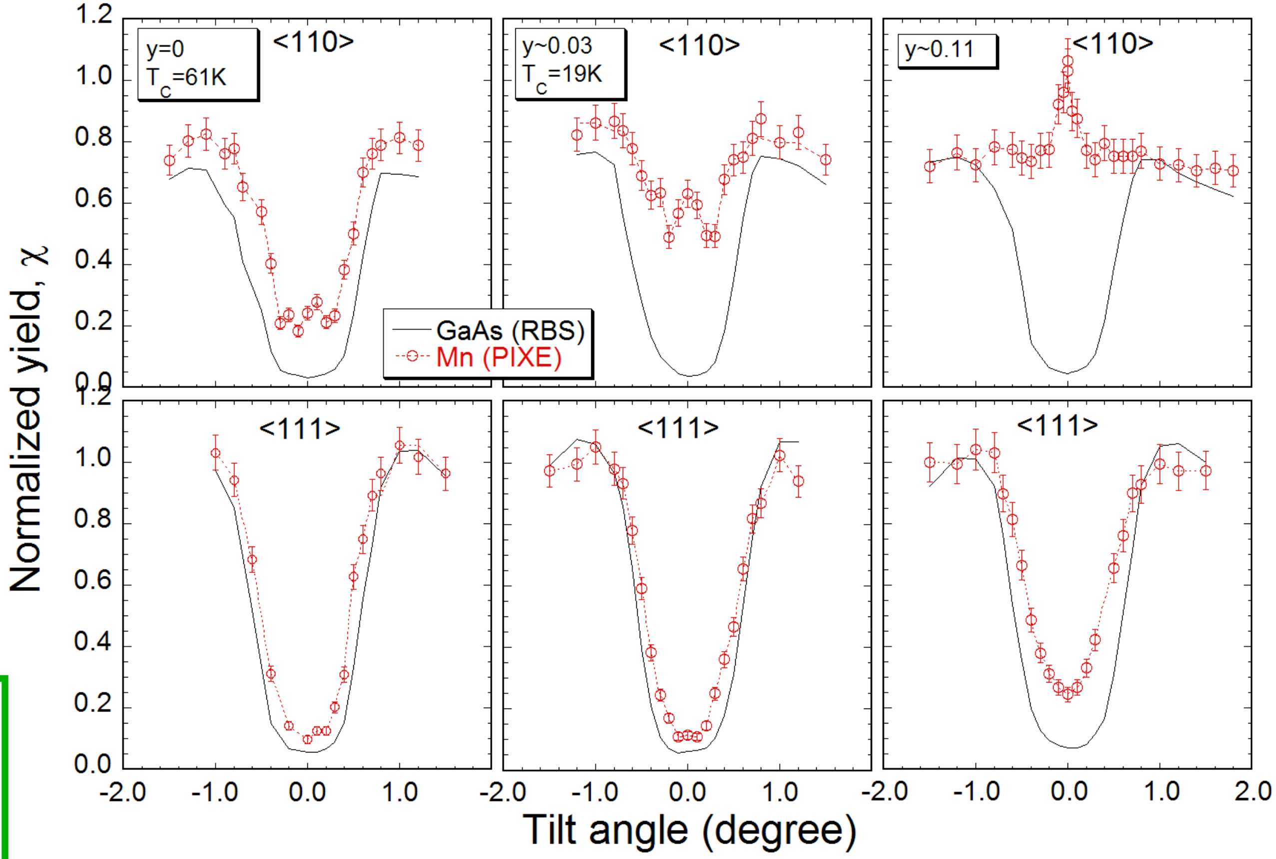


<111>

- 🟢 Cation
- ○ Anion
- 🔵 Tetrahedral interstitials
- 🔴 Hexagonal interstitials

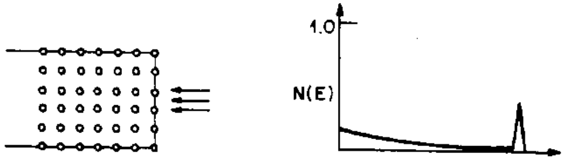
Channeling RBS/PIXE:

- -presence of interstitial Mn in GaAs
- -$[Mn_I]$ increases with Be doping
- -Mn_I reduces T_C

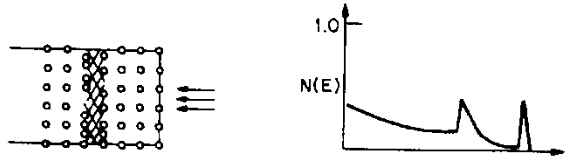


K. M. Yu et al. 2003.

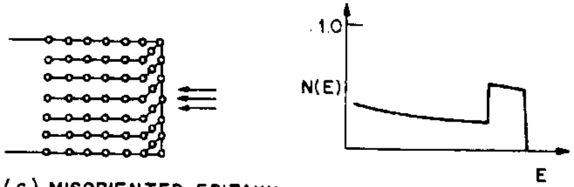
Homo- and Heteroepitaxy



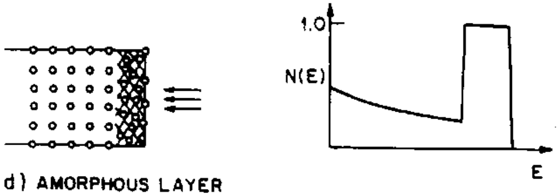
(a) PERFECT HOMOEPITAXY



(b) INTERFACE DISORDER



(c) MISORIENTED EPITAXY



(d) AMORPHOUS LAYER

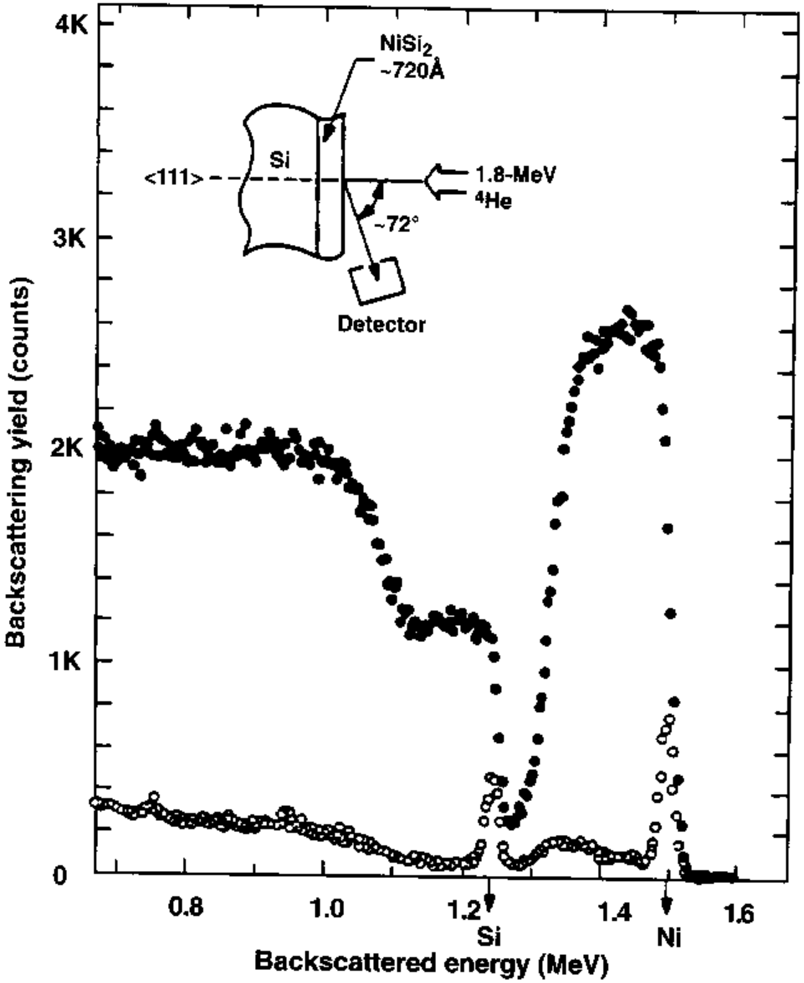
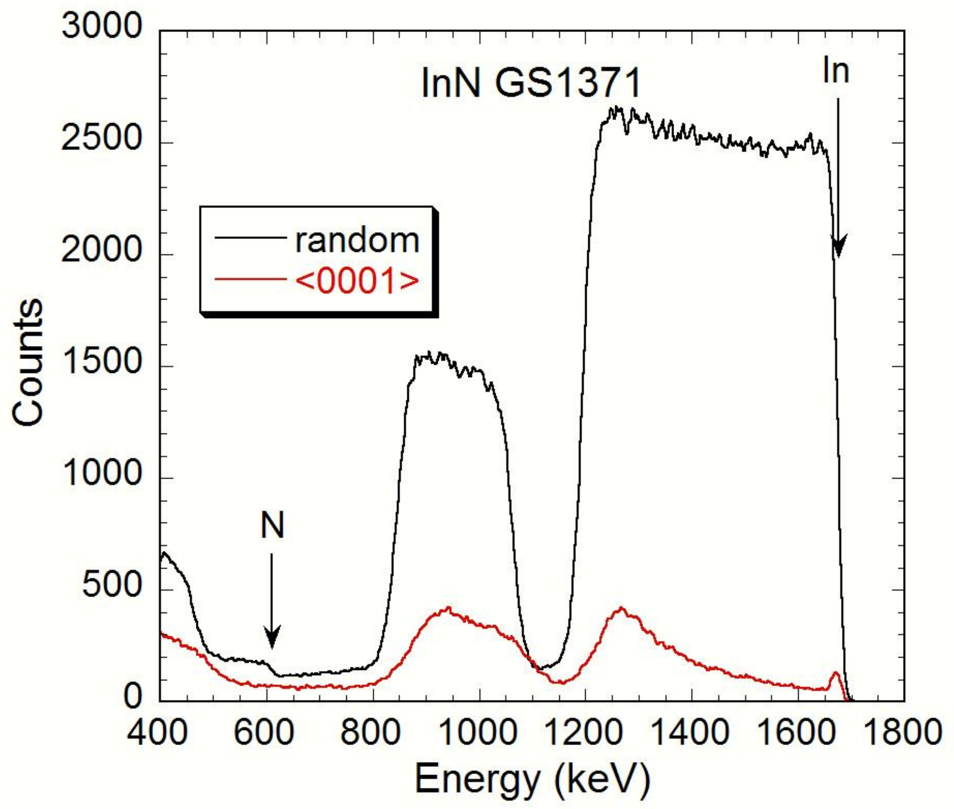


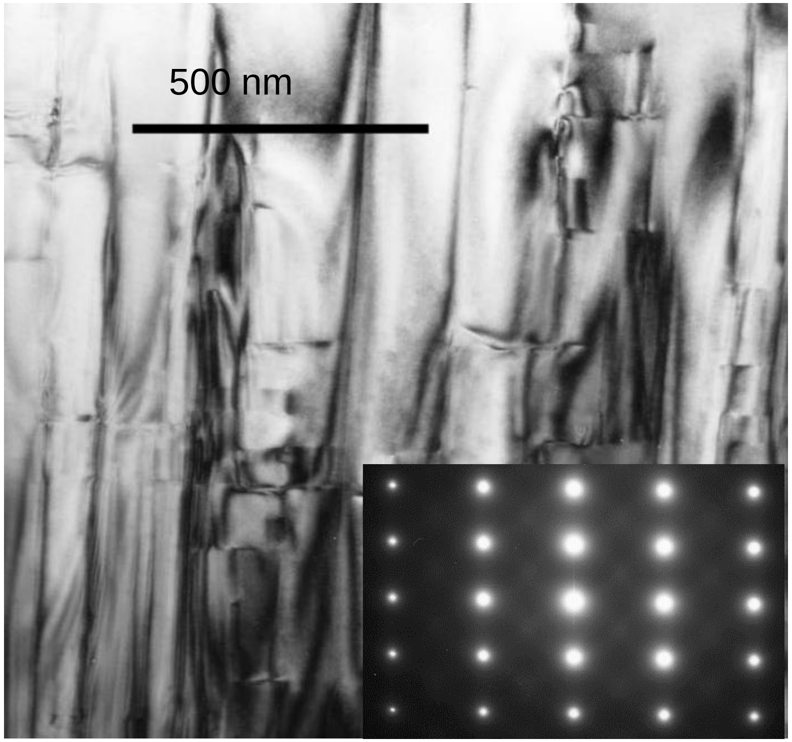
FIG. 10.24. Random and <111> channeling spectra for a 72 nm NiSi$_2$ epitaxial film on a (111) Si substrate (from Chiu *et al.*, 1980).

Channeling: Heteroepitaxy



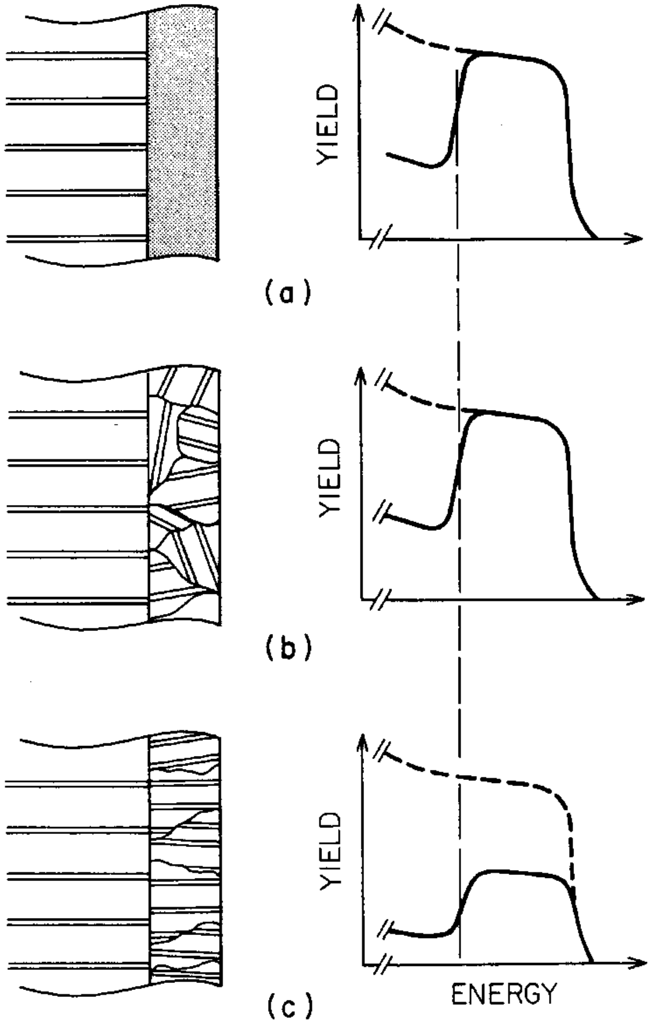
~530nm InN on 210 nm GaN

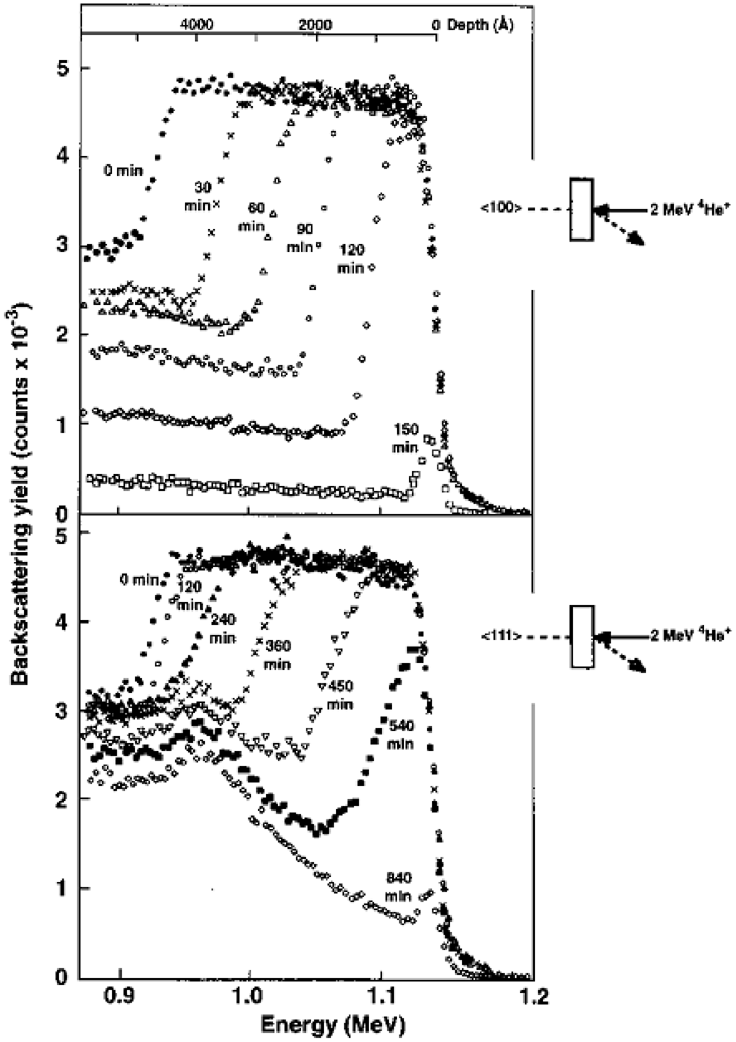
K. M. Yu et al., LBNL 2004.



Z. Liliental-Weber

Amorphous layer analysis





Strengths of Ion Beam Analysis Techniques

- Simple in principle
- Fast and direct
- Quantitative (without standard for RBS)
- Depth profiling without chemical or physical sectioning
- Non-destructive
- Wide range of elemental coverage
- No special specimen preparation required
- Can be applied to crystalline or amorphous materials
- Simultaneous analysis with various ion beam techniques (RBS, PIXE, channeling, etc.)

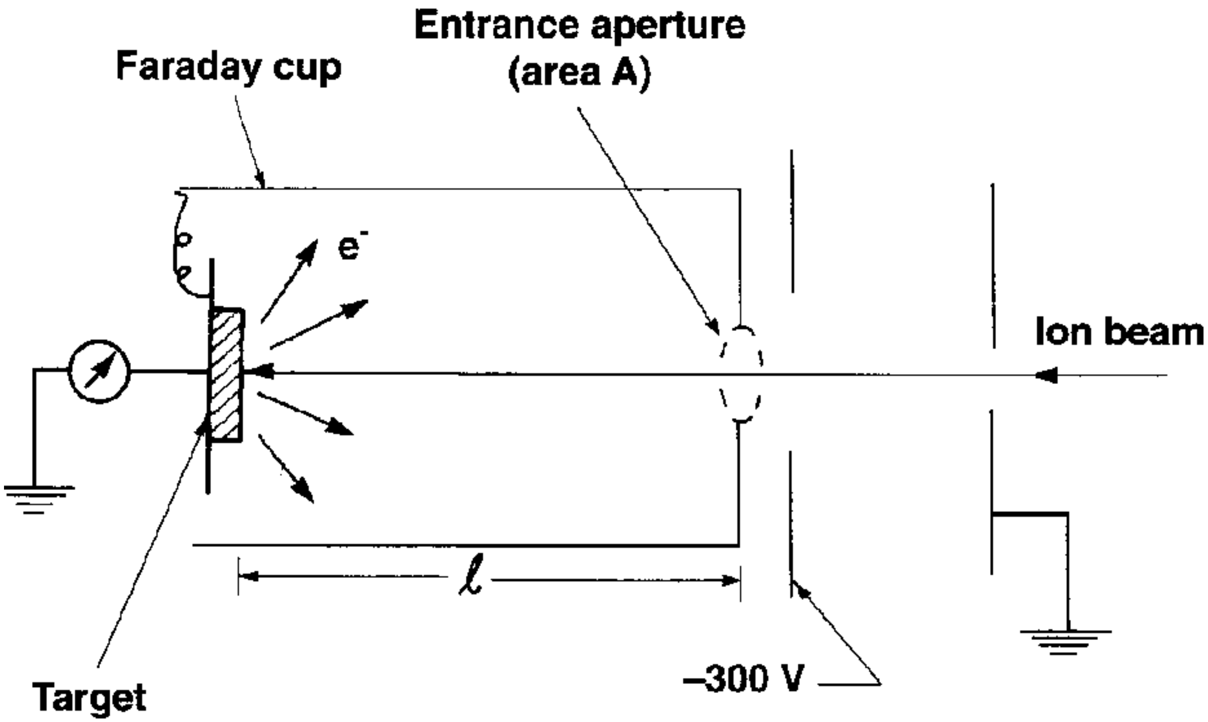
Pitfalls in IBA

Yield: $$\boldsymbol{Y_i = N_i\left(\frac{d\sigma(E, \dots)}{d\Omega}\right) * Q\Omega}$$

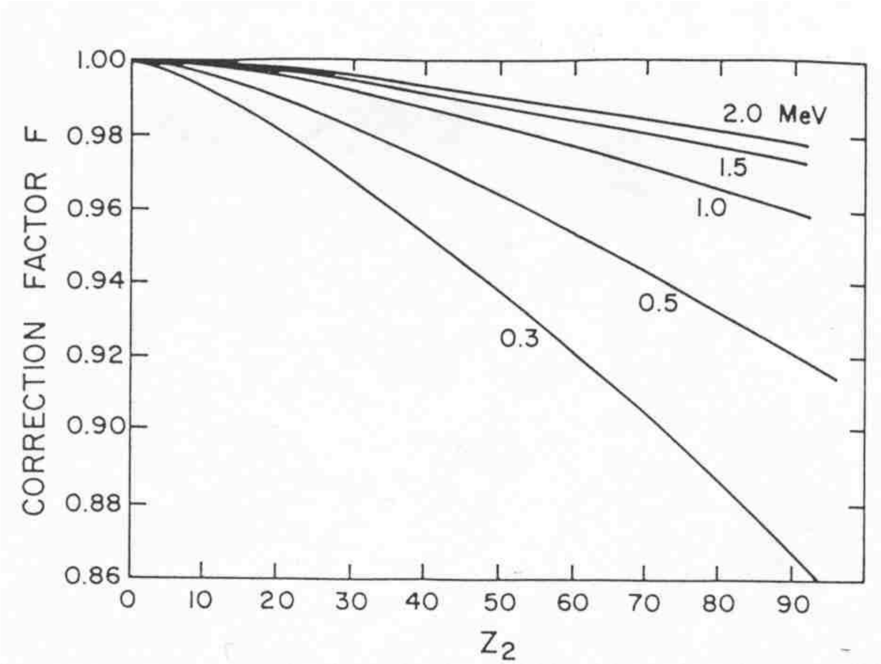
- Q-total charge
  - accurate charge integration
- **Ω-solid angle**
  - dσ/dΩ- detection angle, double/plural scattering
- Other issues:
  - Radiation damage
  - Sputtering
  - Detector response
  - Surface roughness
  - Non-uniformity
  - Charging on insulators
  - Count rate effects

Charge integration

- Charge Integration
  - Accurate charge integration is important for absolute quantitative measurements
    - Good faraday cup design



Deviation from Rutherford scattering



Correction factor F, which describes the deviation from pure Rutherford scattering due to electron screening for He^+ scattering from atoms, Z_2, at variety of incident kinetic energies.

Electronic screening Rutherford Nuclear Interaction

Energy

- At very high energy and very low energy, scattering will deviate from the Rutherford type.
- At low energy : screening of e^- must be considered
- At high energy : nuclear short range force will enhance the cross-section, the so-called "resonance scattering."

Charging effect for insulating samples

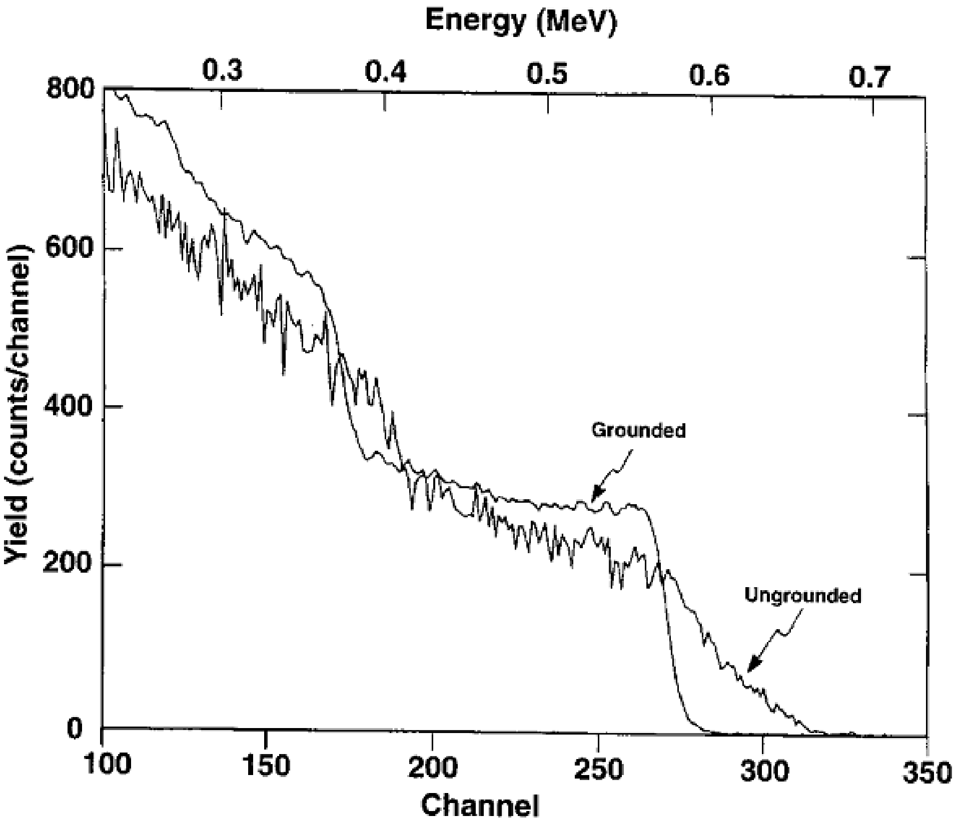


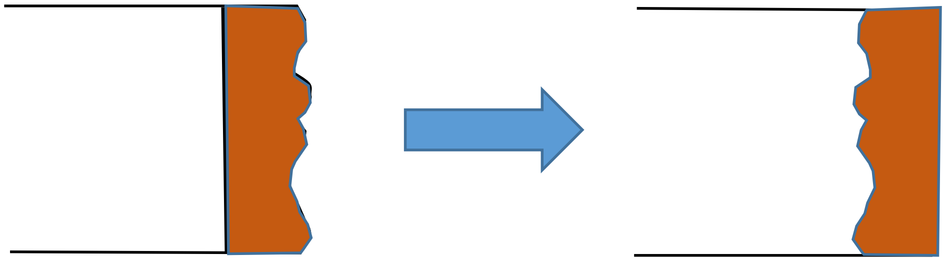
FIG. 12.8. Surface charging effect. Comparison of RBS spectra from a quartz target using 1 MeV ^{4}He: a) ungrounded; b) grounded via a thin conductive surface layer of graphite by rubbing a pencil lightly across the surface (Almeida and Macauley-Newcombe, 1991).

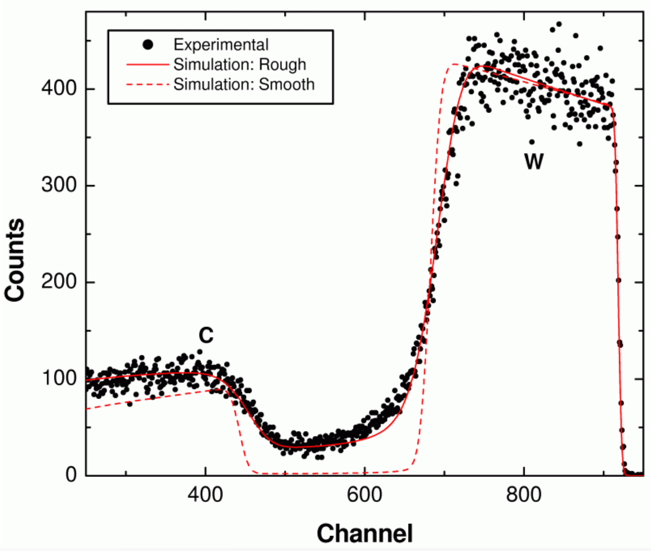
Severely distort the RBS spectrum

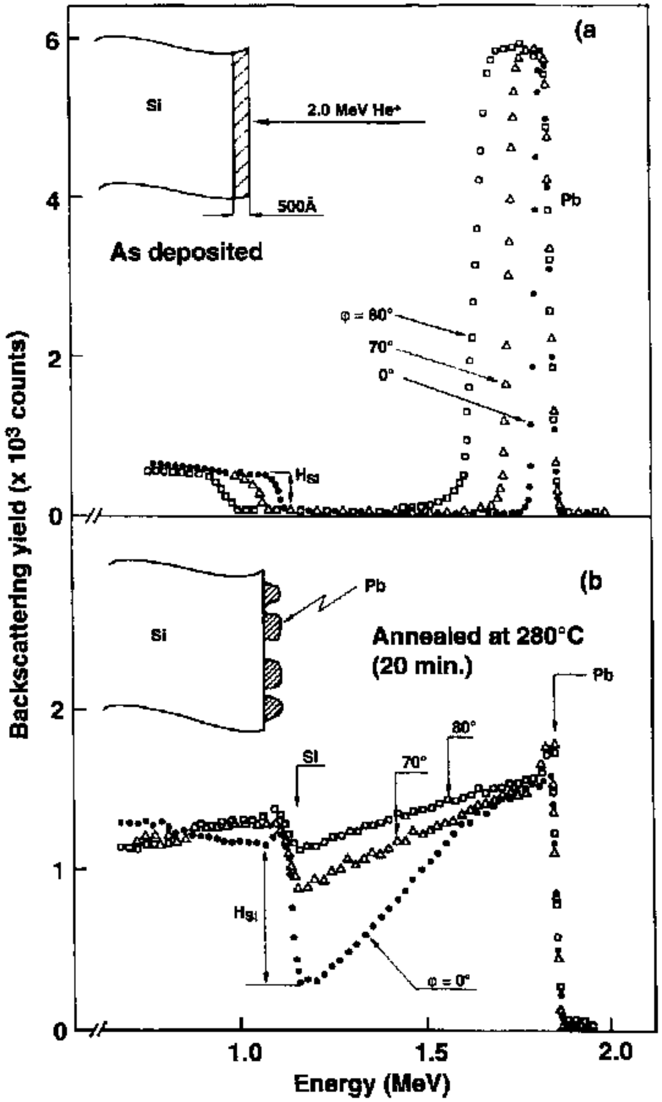
- Provide a supply of low-E electrons from a small, hot filament located nearby
- Coating the surface with a very thin layer of conducting material

Target non-uniformity

- Surface roughness and interface roughness cannot be distinguished
- Target non-uniformity will resemble diffusion







Campisano et al., 1978