Ion Scattering Techniques for Material Analysis

Material Physics IF1602, Autumn 2010

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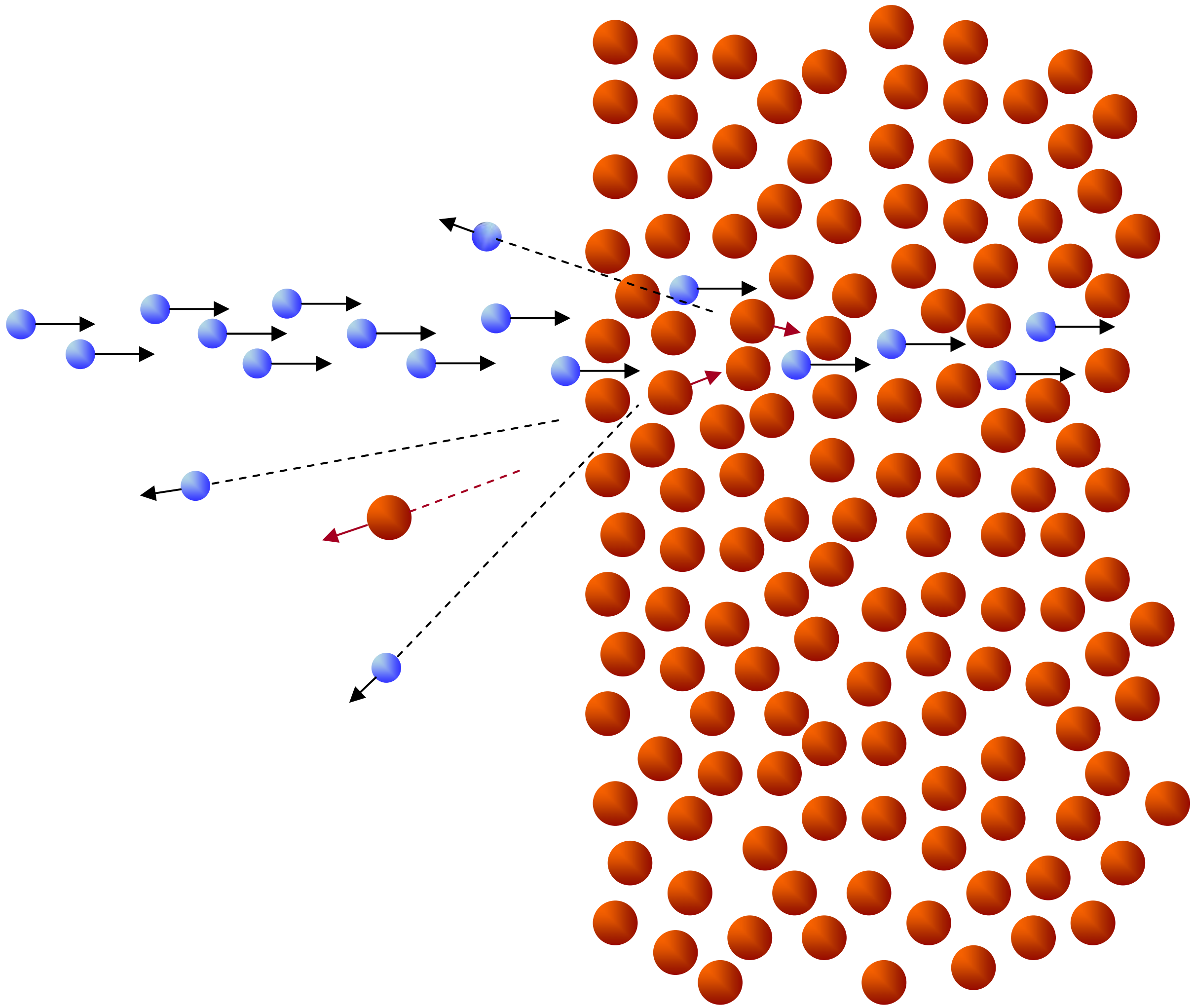

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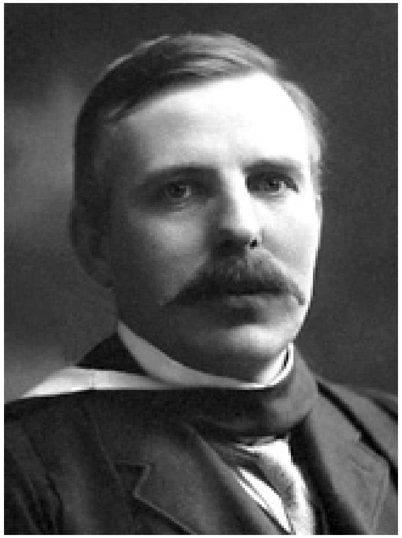
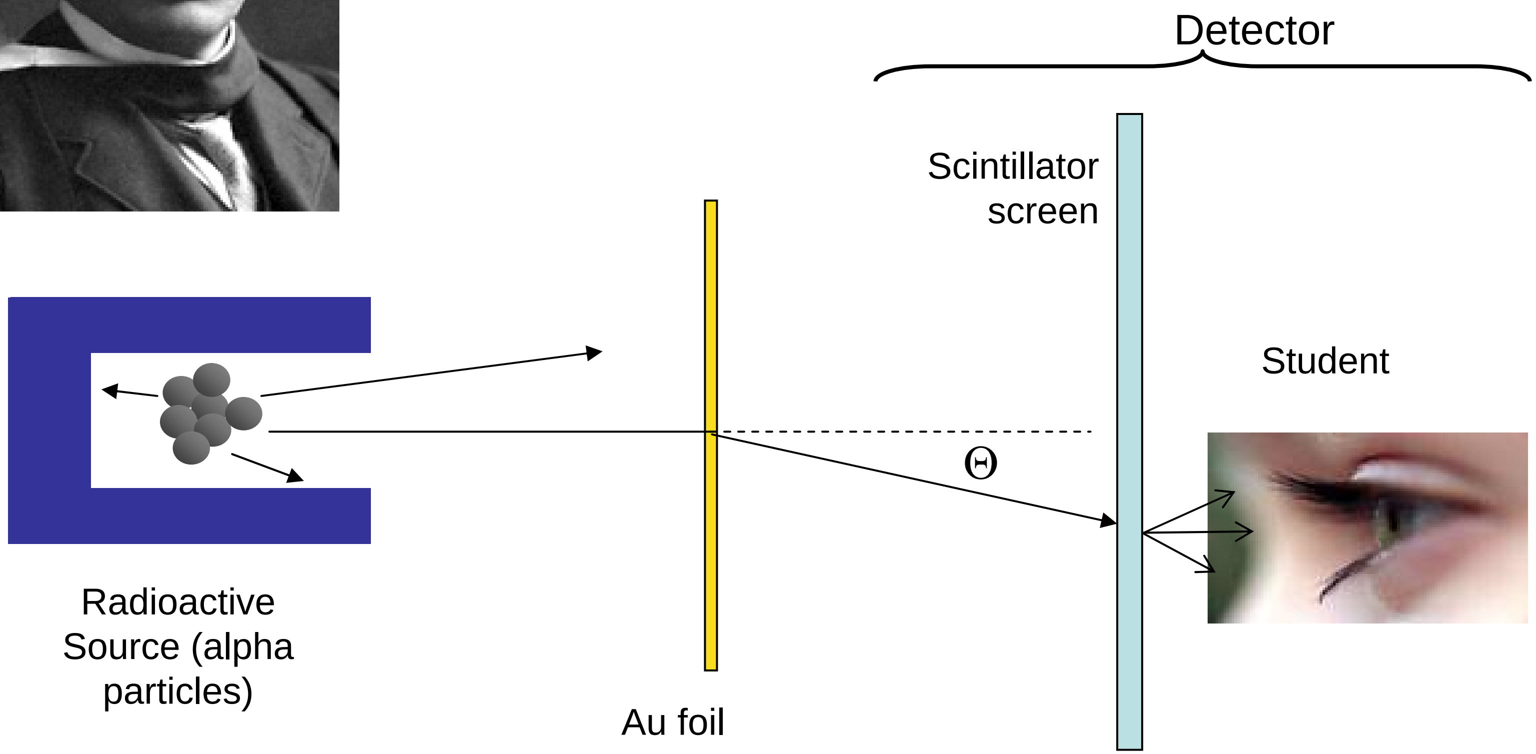
Outline

1. History
2. Energetic ion interaction with matter
3. Equipment
4. Other ion scattering techniques
5. Basic RBS theory
6. RBS on-line demonstration using Uppsala tandem accelerator and internet

Brief History



Ernest Rutherford 1871-1937
Nobel Prize in Chemistry 1908



”It was quite the most incredible event that ever happened to me in my life.
It was as incredible as if you fired a 15 inch shell at a piece of tissue paper and it came back and hit you.”
Ernest Rutherford, 1911

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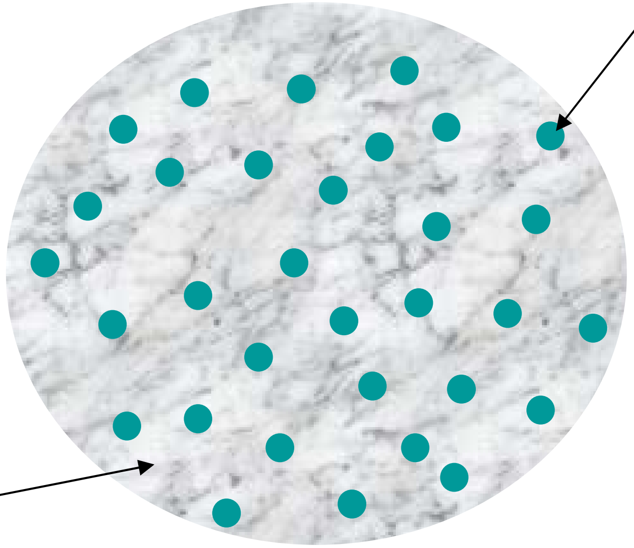
Atom Models

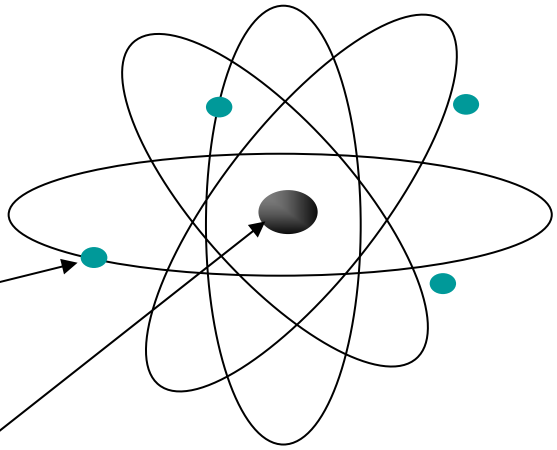
Electron (negative charge)

Thomsons plum pudding model of the atom



Positive distributed charge and mass

Rutherfords experiment led to Bohr's model



Electrons with quantized energies

Positive localized charge and mass (nucleus)

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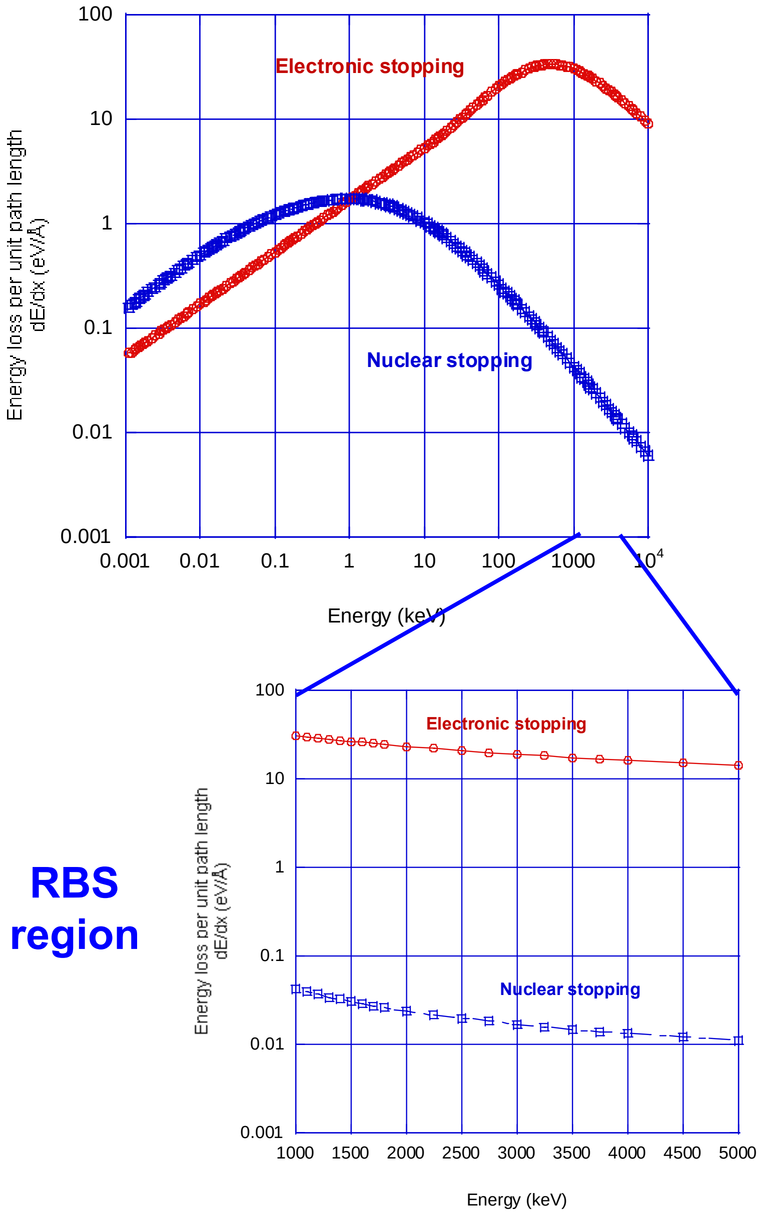
Stopping of He in silicon



RBS region

<u>Electronic stopping</u>

Energy given up to the lattice electronic system. No permanent damage (in conducting matter).

<u>Nuclear stopping</u>

Elastic collisions between incoming ion and screened lattice nuclei. Occurs predominantly towards the end of the ion track, where the material will be permanently damaged.

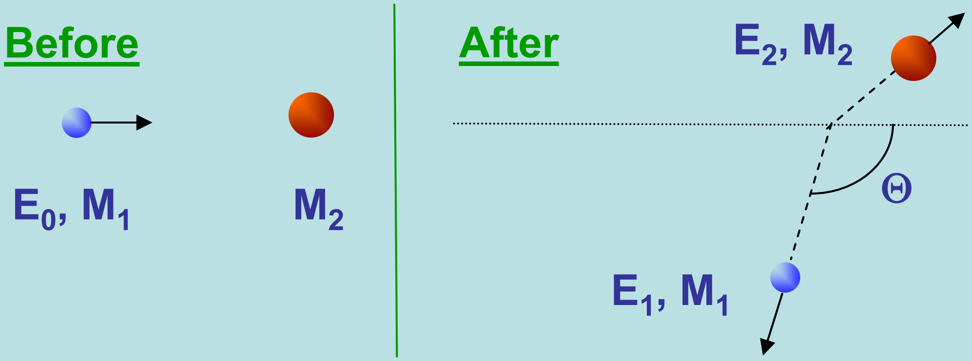
<u>Typical energy ranges for IBA</u>

- **Secondary ion mass spectrometry (SIMS)**
  Primary ion energy: 5 < E < 20 keV

- **Rutherford backscattering spectrometry (RBS)**
  Primary ion energy: 1 < E < 5 MeV

- **Medium energy ion scattering (MEIS)**
  Primary ion energy: 50 < E < 500 keV

Kinematics



Conservation of E and p

$E_1 = k\,E_0$

Kinematic factor $k = k(M_1, M_2, \Theta)$

Energy loss

Electronic stopping is known and roughly constant for small depths

⇨ Depth of the collision can be estimated

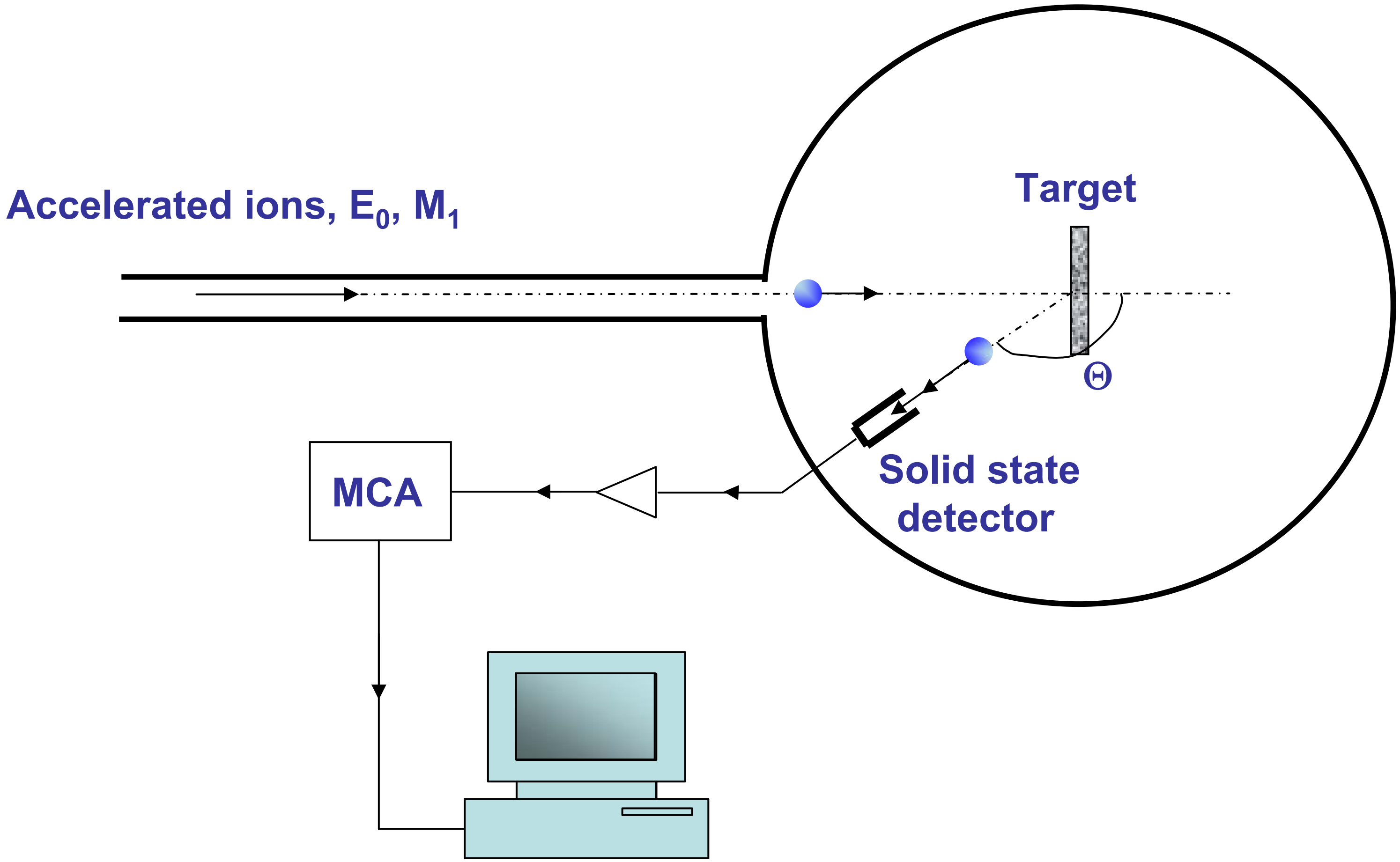
Rutherford scattering

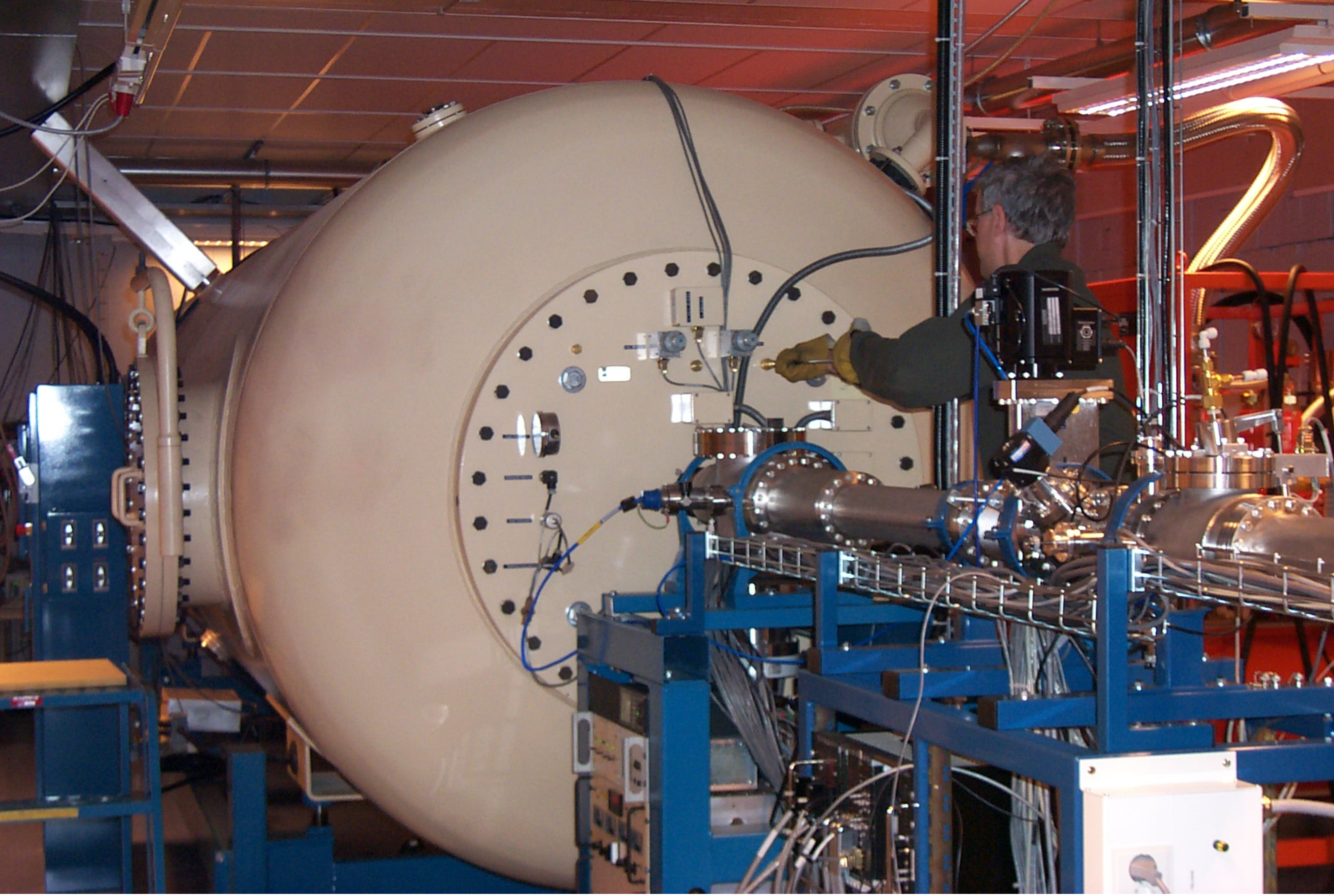
Rutherford calculated the probability for scattering $\sigma = \sigma(\Theta, Z_1, Z_2, E_0)$

⇨ The yield of backscattered particles can be estimated

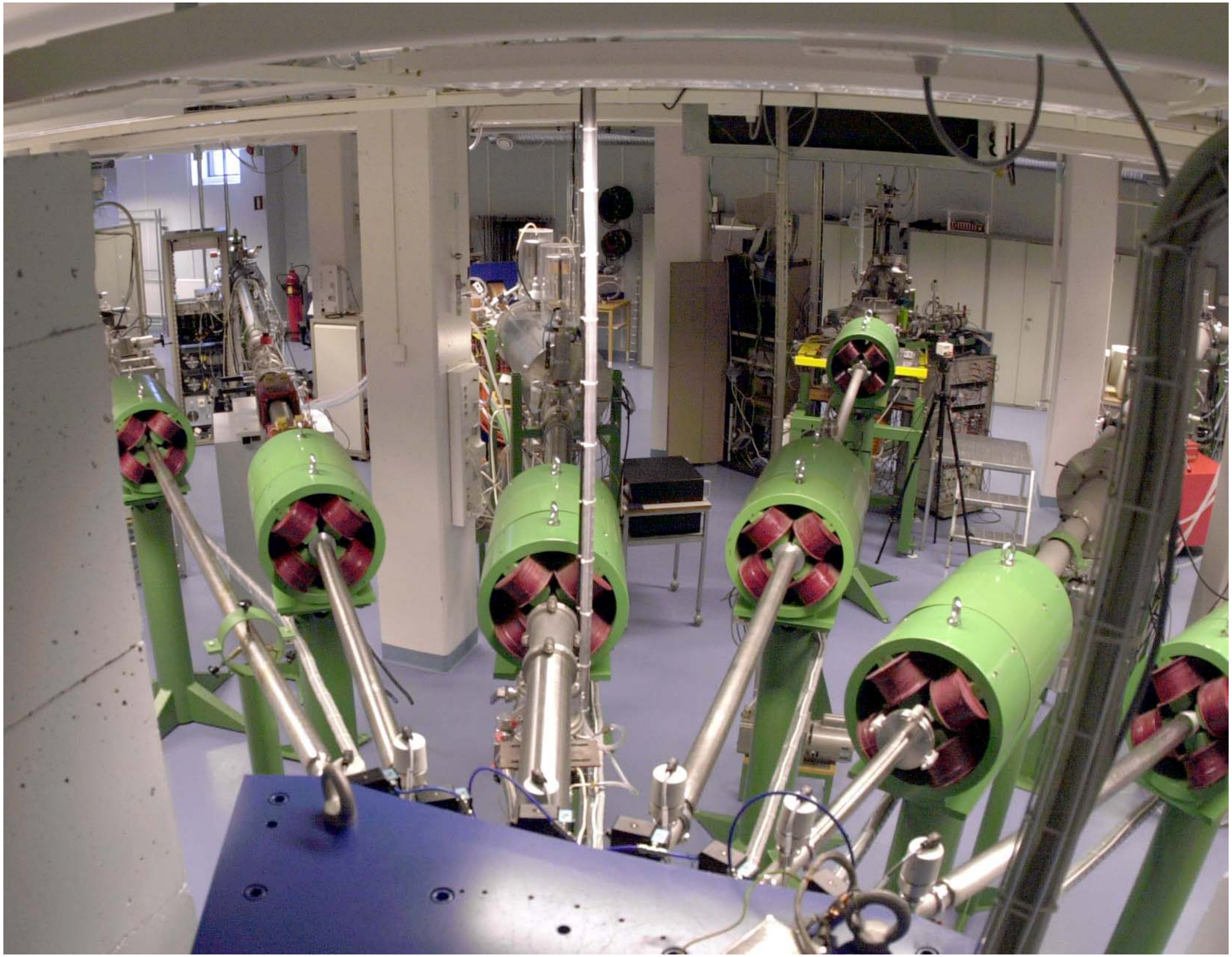
Typical scattering chamber

Backscattering geometry

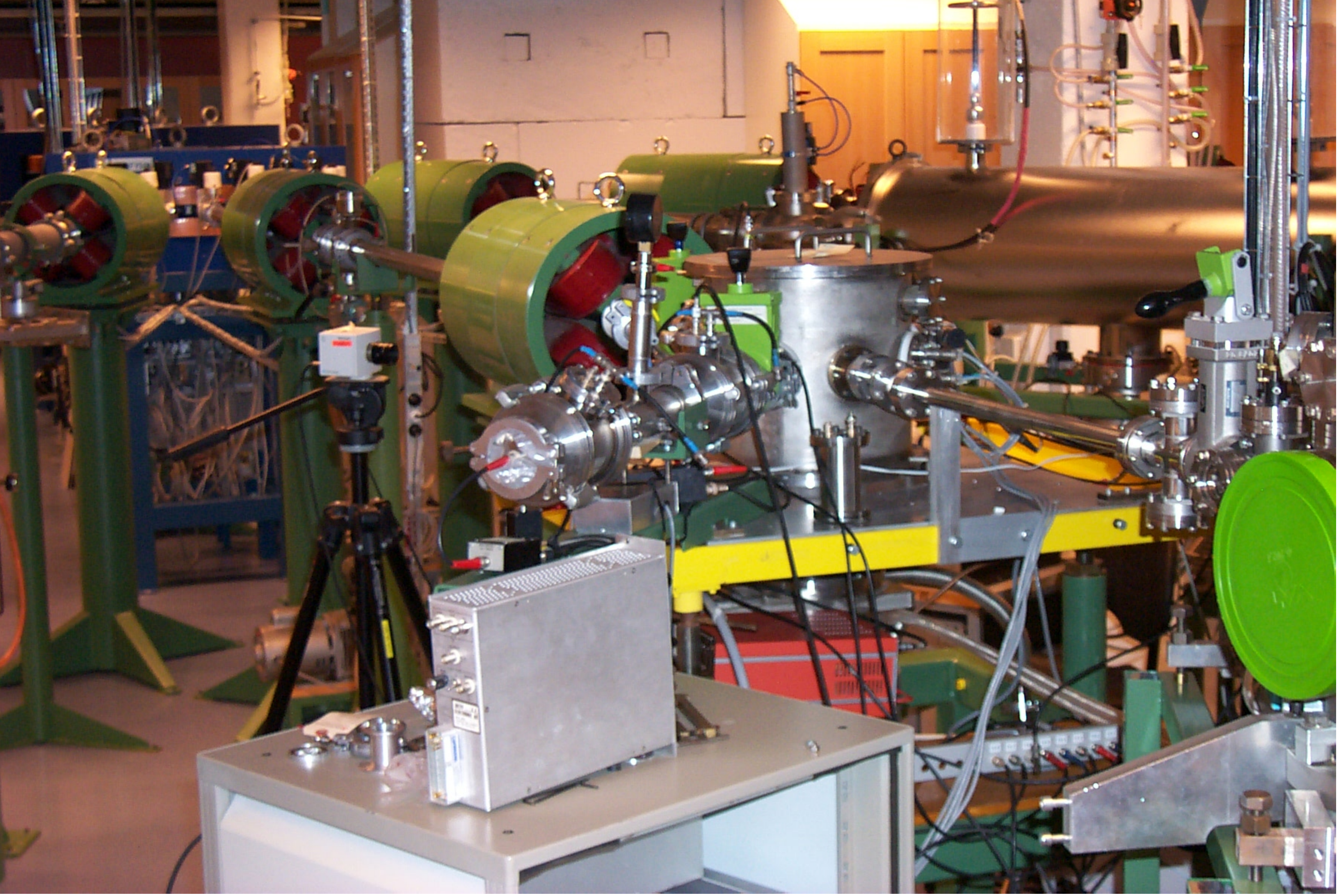




Uppsala 5 MV Pelletron tandem

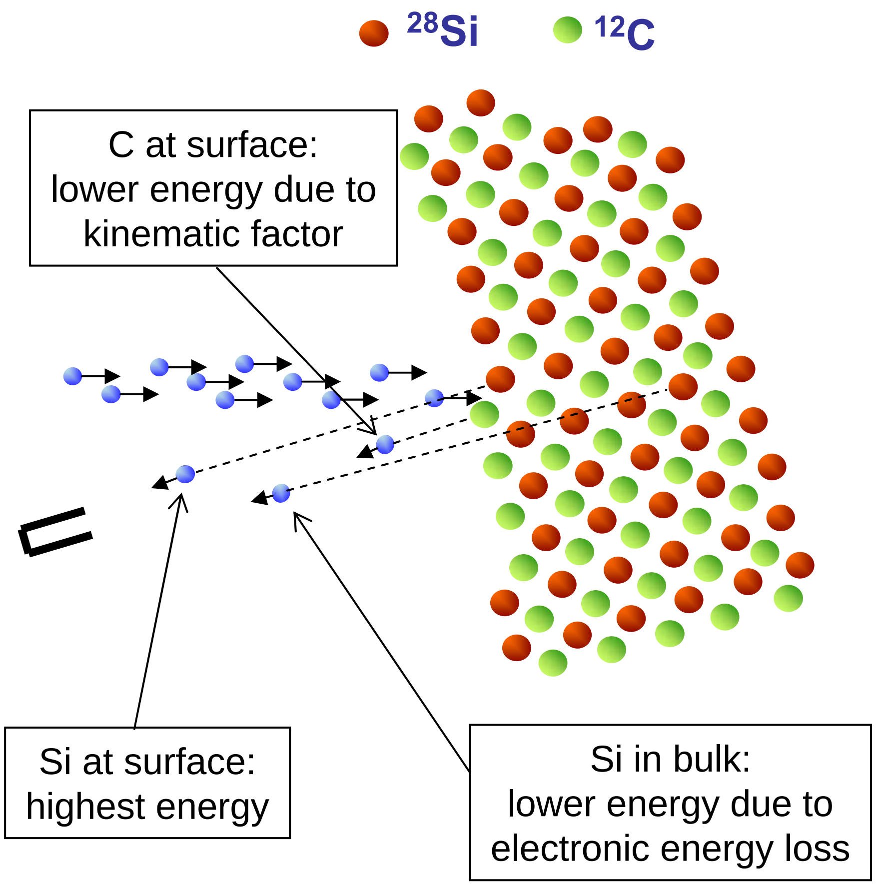


6 beamlines of which 5 are used for analysis

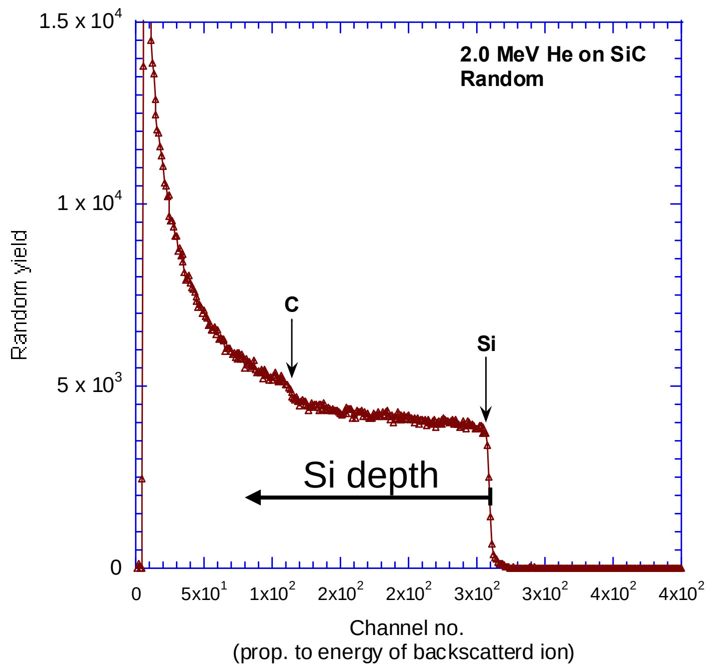


Scattering chamber used for RBS and ERDA

RBS example: 2.0 MeV He on SiC



Resulting spectrum



Data analysis by simulation of spectra

http://www.rzg.mpg.de/~mam/

SIMNRA Home Page - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://www.rzg.mpg.de/~mam/

SIMNRA Home Page
by Matej Mayer

Max-Planck-Institut für Plasmaphysik

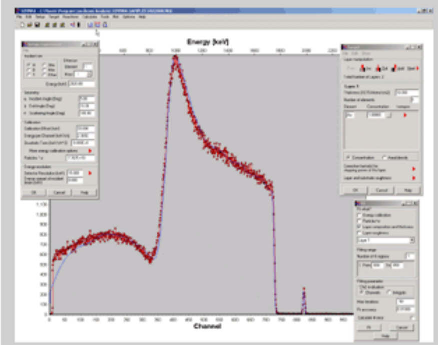
- Introduction
- SIMNRA 6.0 NEW
- RESOLNRA 1.0 NEW
- Examples
- Installation
- Registration/Pricing
- Download
- References
- Citations
- Cross-section data
- What's new
- Site info

INTRODUCTION

SIMNRA is a Microsoft Windows program for the simulation of backscattering spectra for ion beam analysis with MeV ions. SIMNRA is mainly intended for the simulation of non-Rutherford backscattering, nuclear reactions and elastic recoil detection analysis (ERDA). More than 300 different non-Rutherford and nuclear reactions cross-sections for incident protons, deuterons, ^{3}He, ^{4}He and Li-ions are included. SIMNRA can calculate any ion-target combination including incident heavy ions and any geometry including transmission geometry and arbitrary foils in front of the detector.

- Fully graphical user interface
- Available stopping powers: SRIM 2003, Konac et al. (for C and Si targets), Ziegler-Biersack (identical to SRIM 97), Andersen-Ziegler, user defined
- Energy loss straggling: Bohr straggling, Chu correction to Bohr straggling, straggling due to charge state fluctuations, propagation of straggling in thick layers
- Geometrical straggling due to finite beam width and detector aperture
- Multiple small angle scattering, identical to E. Szilágyi's DEPTH code
- Plural large angle scattering
- Surface roughness (rough layers, rough substrate)
- Roughness of foils in front of the detector
- Live time correction and pile-up simulation, pile-up correction of experimental data
- Detector types: Solid-state detectors, thin (transmission) detectors, time-of-flight detectors, electrostatic detectors

Click figure to get a magnified version of the graph



SIMNRA graphical user interface, showing an experimental spectrum (red), a simulated spectrum (blue), and forms for defining experimental setup, target composition, and fit parameters.

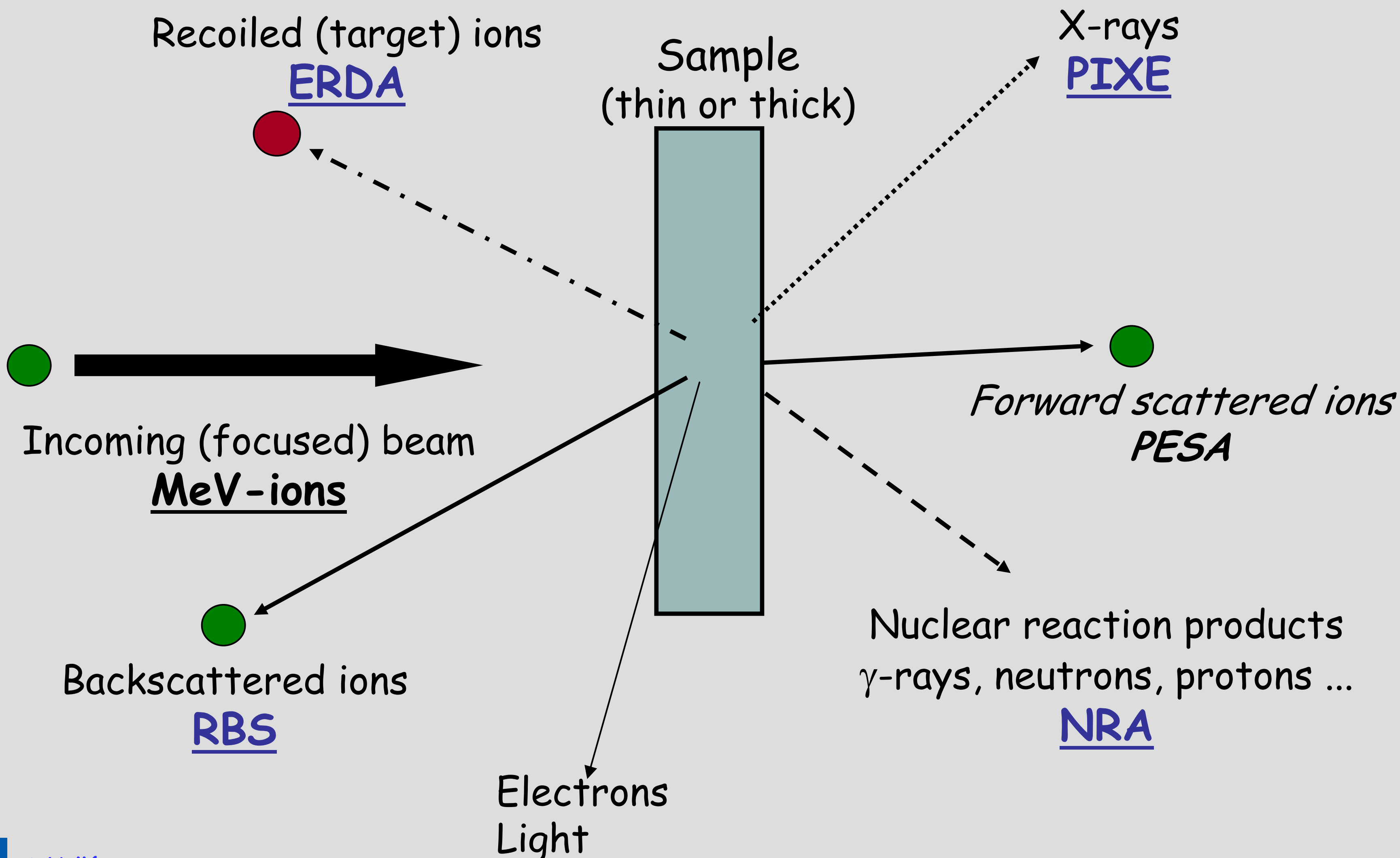
Internet

Start | Removable Disk (E:) | Microsoft PowerPoi... | Eudora | 20080526 | SIMNRA Home Pa... | 20:49

RBS (random) applications and limitations

- MeV random RBS (RBS-r) for thin film analysis
  - **Surface composition**
  - **Trace impurity concentration**
  - **Element identification (heavy element in light matrix)**
  - **Depth profile within ~ μm of target surface**
- Probing depth: ~ a few μm
- Detection sensitivity**:** more sensitive to the heavy element due to larger differential recoil cross section,
  - ~10^{-4} monolayers for ^{207}Pb on ^{12}C, ~2×10^{-2} monolayers for ^{75}As on ^{65}Zn,
- Depth resolution: ∕ ~ 30 nm
- Mass resolution: ~3% at M_2=100

IBA
Ion Beam Analysis

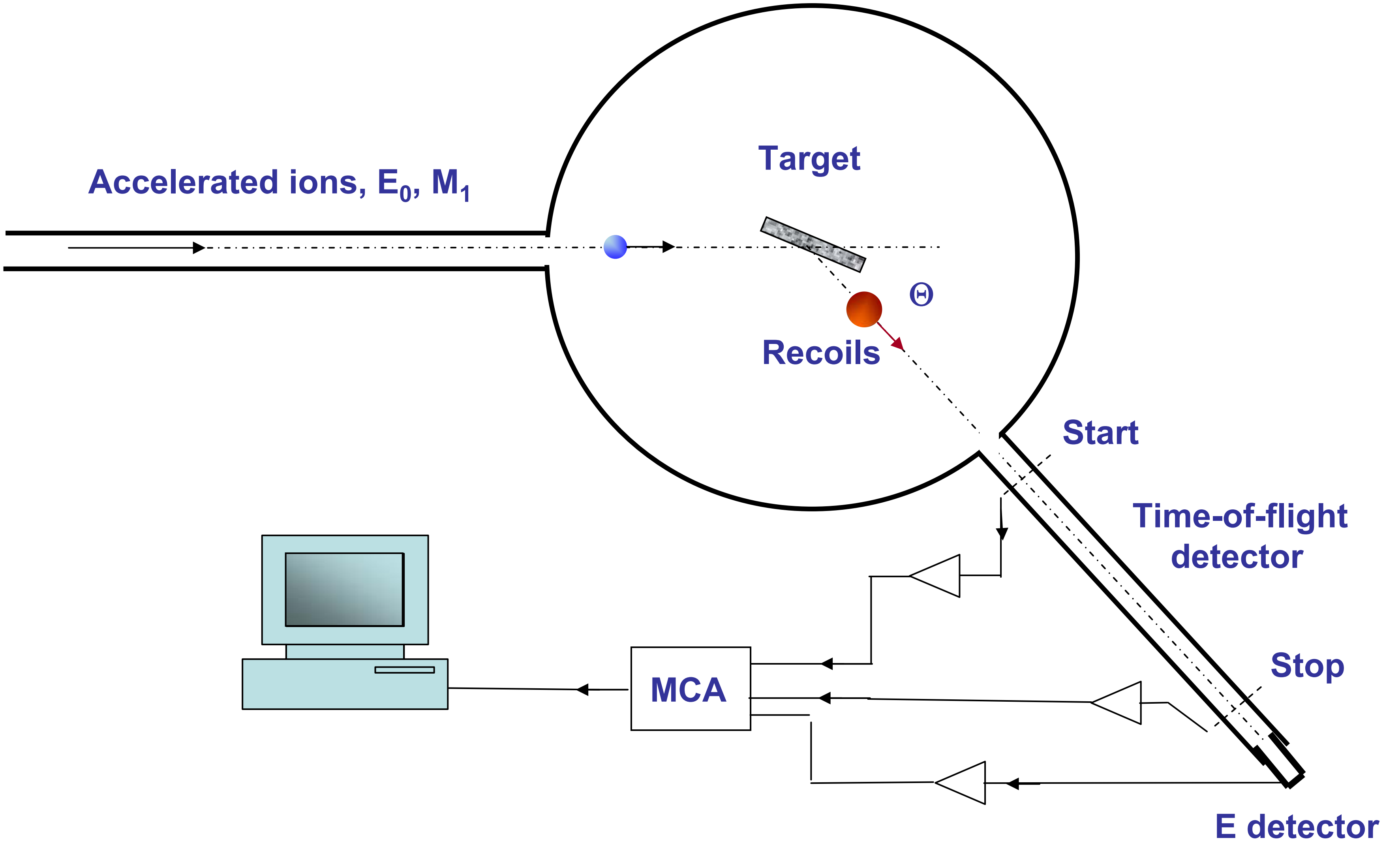


Other IBA varieties

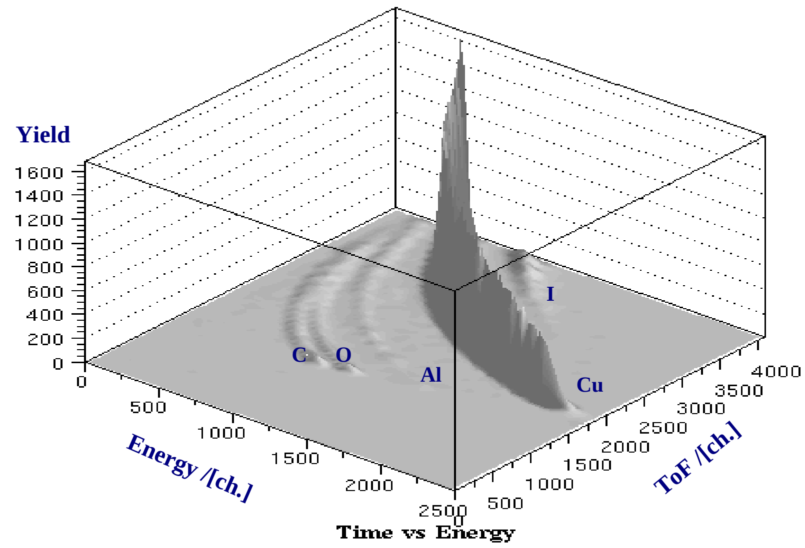
- Rutherford backscattering spectrometry (RBS)
- Secondary ion mass spectrometry (SIMS)
- Elastic recoil detection analysis (ERDA)
- Channeling RBS (RBS-C)
- Nuclear reaction analysis (NRA)
- Medium energy ion scattering (MEIS)

Typical scattering chamber

Recoil detection geometry

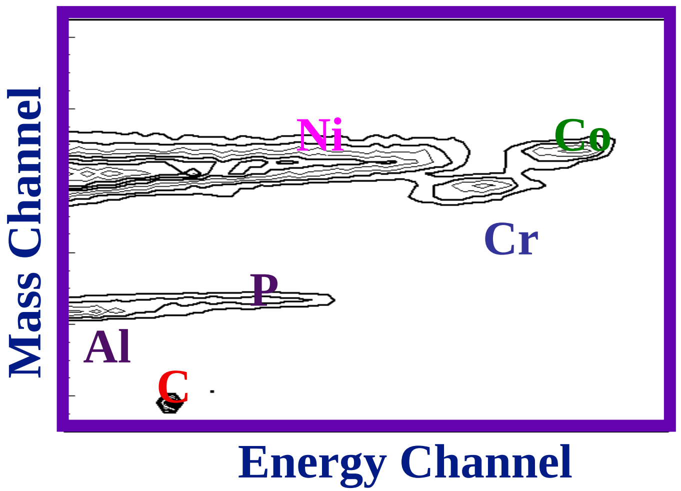


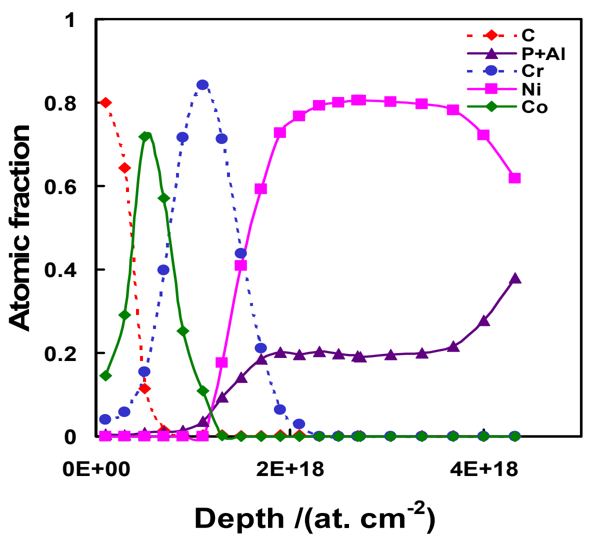
Typical ERDA spectrum
Probing beam: ^{127}I
Target: Cu sample



C/Co/Cr/Ni-P/Al multilayer structure from a standard hard disc

Data analysis with CONTES



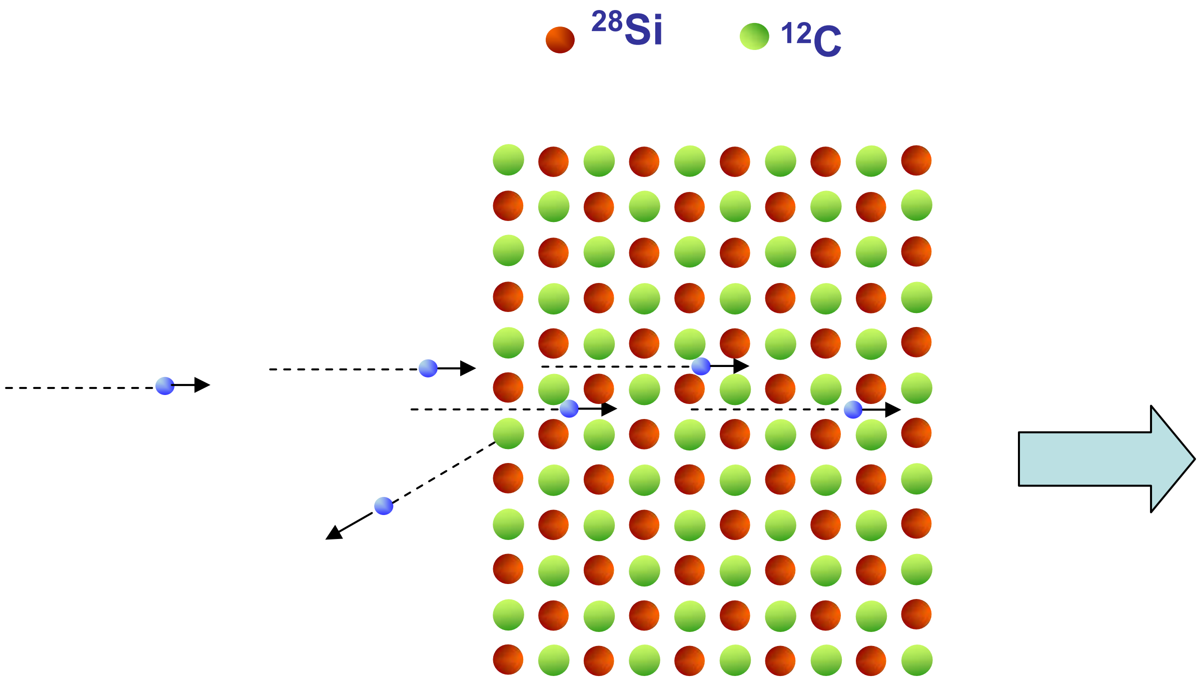


ERDA applications and limitations

- Signals from elements with overlapping energy distributions can be resolved (e.g., Si in $Al_xGa_{1-x}As$).
- Depth profiles of heavy and light elements can be measured simultaneously (e.g., the Pd/InP system).
- **Probing depth:** ~ a few μm
- **Detection sensitivity: almost constant.** When $M_1>M_2$, the cross section is almost independent of recoil
- **Element sensitivity:** ⁄0.1%
- **Depth resolution:** ⁄ 20 nm
- **Elemental separation power:** ΔM/M ⁄5% at medium mass elements

RBS Channeling mode

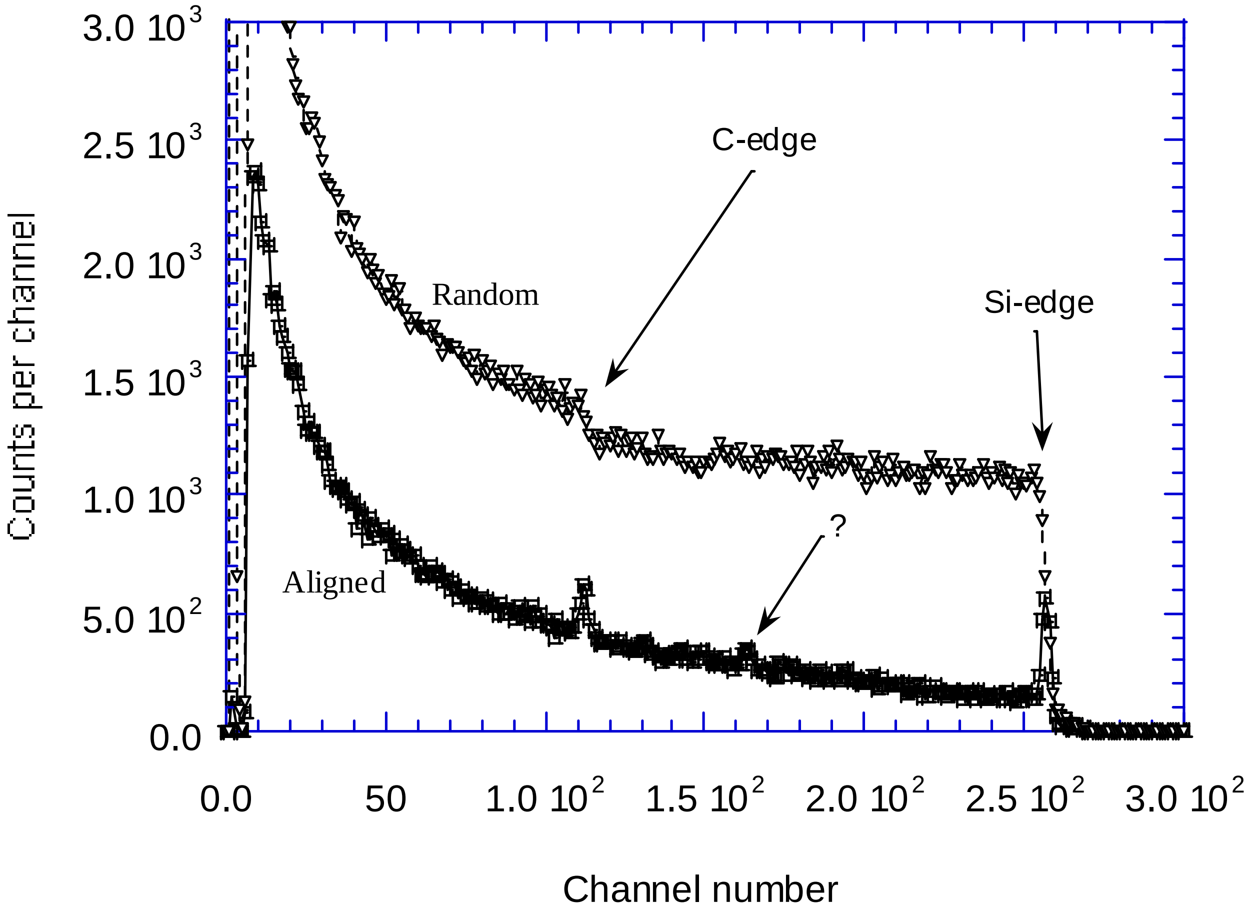
Probe beam aligned with a crystal axis



The backscatter yield drops to less than 5% compared to random incidence.

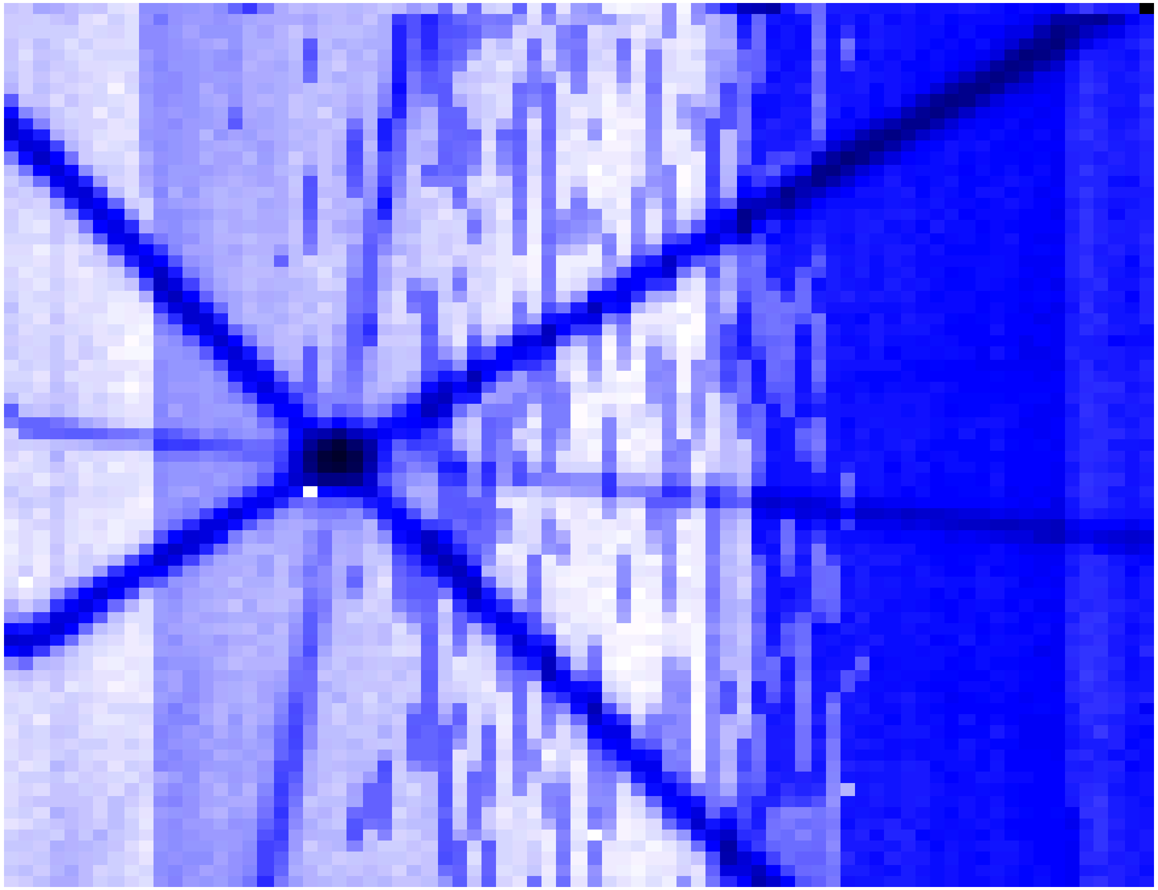
Channeling RBS

Beam aligned with SiC (0001) direction



Channeling RBS

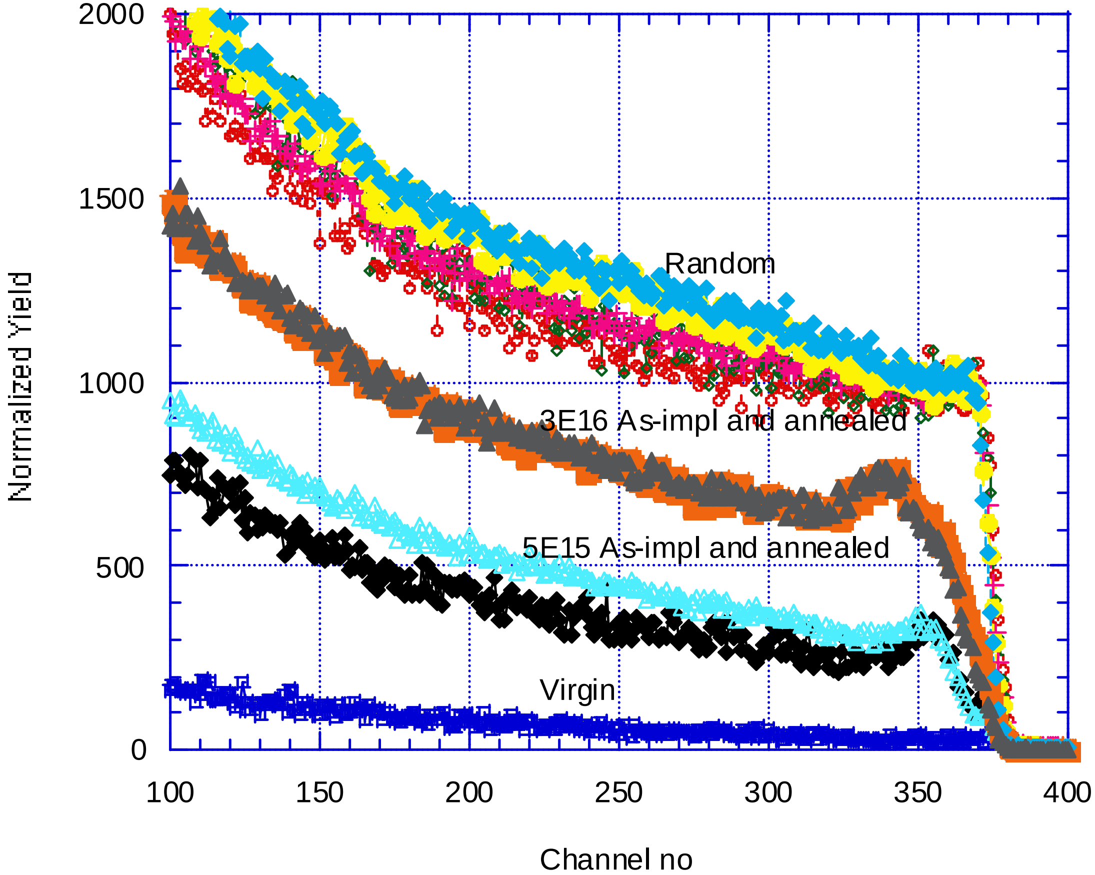
Mapping of Si(100) surface



Scan: ±3.8° in 0.1° interval by 2.4 MeV $^4He^+$

Channeling RBS

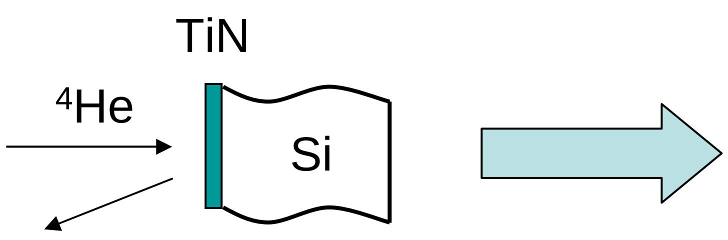
Implantation damage in ZnO

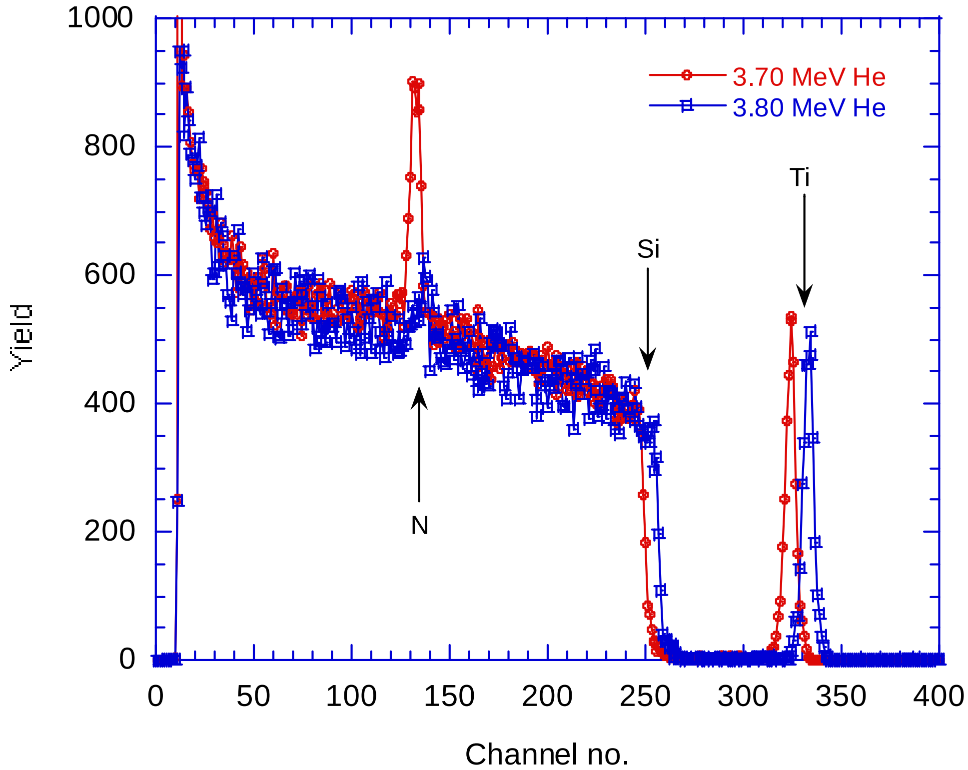


Nuclear Reaction Analysis NRA

Example of non-Rutherford cross sections
Resonance (enhanced cross section) at 3.70 MeV

$^{14}N\ (\alpha,\alpha)\ ^{14}N$





Conclusions

- ♦ Ever since Rutherford discovery, energetic ions beams have been used to probe matter.
- ♦ Standard RBS makes it possible to investigate elemental content, composition and element depth profiles of thin films.
- ♦ The technique is quantitative since the following are well known:
  - Kinematics
  - Energy loss
  - Rutherford cross section (probability for scattering)
- ♦ Many varieties of IBA exists.

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