Ion Beam Analysis

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The 9th Summer School in JINR

Frank Laboratory of Neutron Physics

Joint Institute For Nuclear Research (JINR)

Under supervision of

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OUTLINE

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2.1 The Experimental Chamber for analytical methods in Frank Laboratory

3. Basic Physical Concepts of RBS method

3.1 Kinematic Factor K

3.2 Scattering Cross Section

4. Rutherford Backscattering Spectroscopy (RBS)

5. Elastic Recoil Detection Analysis (ERD)

6. Nuclear Reaction Analysis (NRA)

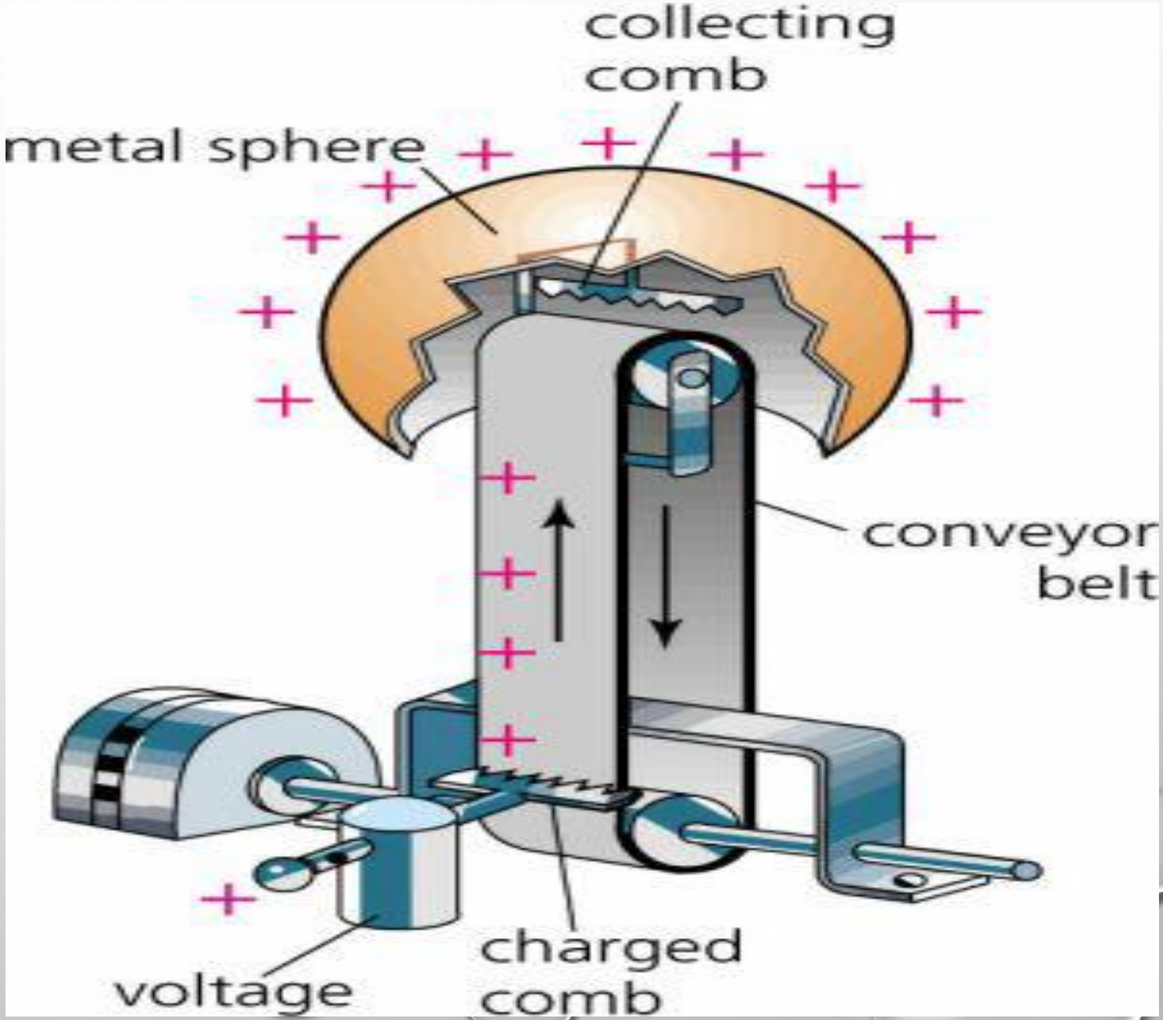
AIM OF PROJECT

Analysis of contents and depth distribution of different elements in the near surface layers of solids using:

- **R**utherford **B**ackscattering **S**pectrometry (**RBS**)
- **E**lastic **R**ecoil **D**etection (**ERD**)
- **N**uclear **R**eaction **A**nalysis **(NRA)**

VAN DE GRAFF ACCELERATOR

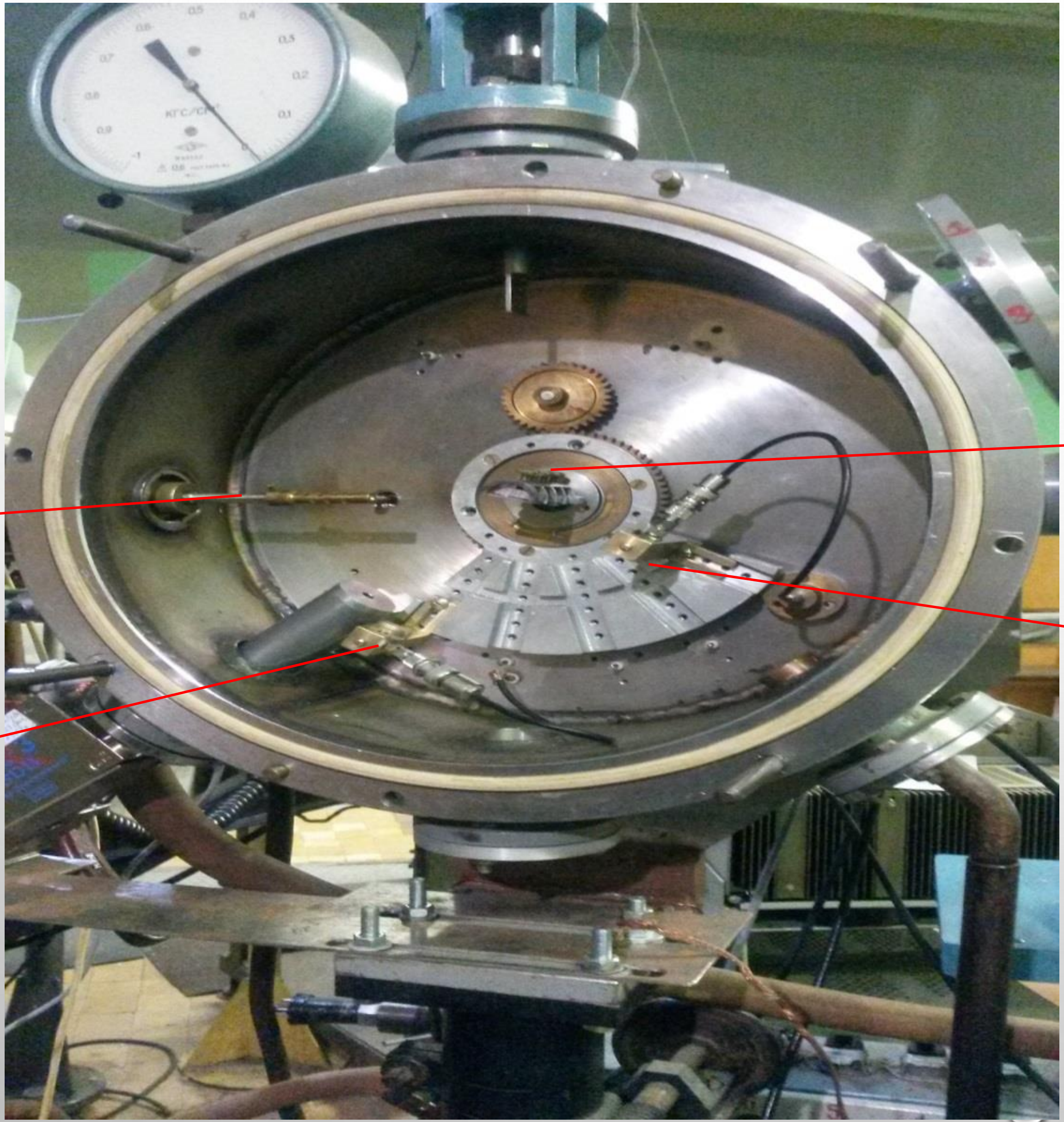
- We used as a particle accelerator, an ion source is located inside the high-voltage terminal.
- Ions are accelerated from the source to the target by the electric voltage between the high-voltage supply and ground.



VAN DE GRAFF ACCELERATOR IN FRANK LABORATORY

- **Produces the beams of helium ions and protons with energy in regions 0.9- 3.5 MeV**
- **Helium intensity less than 10 μA and proton intensity up to 30 μA.**
- **The accelerator belt moves at 20 m/s**
- **The accelerator is placed in a tank under pressure of 10 atmospheres of dry nitrogen.**
- **The accelerator EG-5 has six beam lines.**

The experimental chamber for analytical methods in Frank Laboratory



Holder of Targets

Collimator of beam

ERD detector

RBS detector

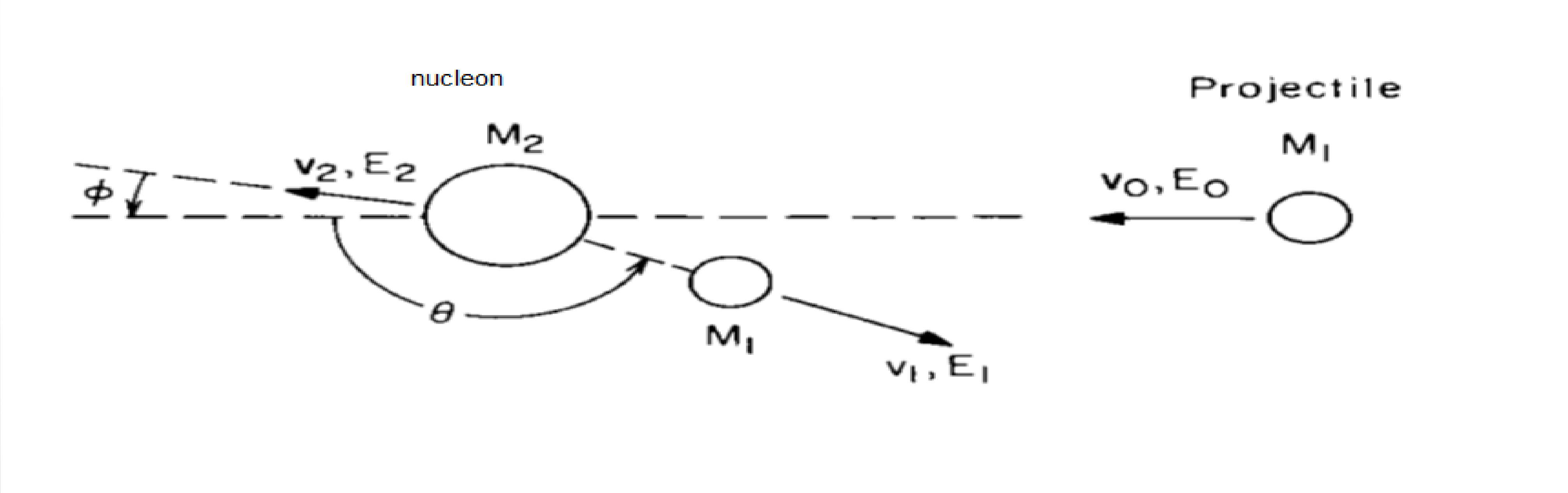
Basic Physical Concepts

1. Energy transfer from a projectile to a target nucleus in an elastic two body collision.

2. It is assumed of such a two-body collision. This leads to the concept of *scattering cross section* and to the capability of quantitative analysis of atomic composition.

3. The energy loss of an atom moving through a dense medium. This process leads to the concept of *energy straggling* and to a limitation in the ultimate mass and depth resolution of backscattering spectrometry.

KINEMATIC FACTOR *K*



$$\tfrac{1}{2}M_1{v_0}^2 = \tfrac{1}{2}M_1{v_1}^2 + \tfrac{1}{2}M_2{v_2}^2,$$

$$M_1v_0 = M_1v_1\cos\theta + M_2v_2\cos\phi,$$

$$0 = M_1v_1\sin\theta - M_2v_2\sin\phi.$$

KINEMATIC FACTOR *K Equation*

$$K = E_1/E_0$$

$$K_{M_2} = \left[\frac{(M_2{}^2 - M_1{}^2 \sin^2\theta)^{1/2} + M_1 \cos\theta}{M_2 + M_1}\right]^2$$

Scattering Cross Section

$$A = \sigma\Omega \cdot Q \cdot Nt$$

$$\begin{pmatrix}\text{number of} \\ \text{detected particles}\end{pmatrix} = \sigma\Omega \cdot \begin{pmatrix}\text{total number of} \\ \text{incident particles}\end{pmatrix} \cdot \begin{pmatrix}\text{number of target} \\ \text{atoms per unit area}\end{pmatrix}$$

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{4E}\right)^2 \frac{4}{\sin^4\theta} \frac{\{[1-((M_1/M_2)\sin\theta)^2]^{1/2} + \cos\theta\}^2}{[1-((M_1/M_2)\sin\theta)^2]^{1/2}}$$

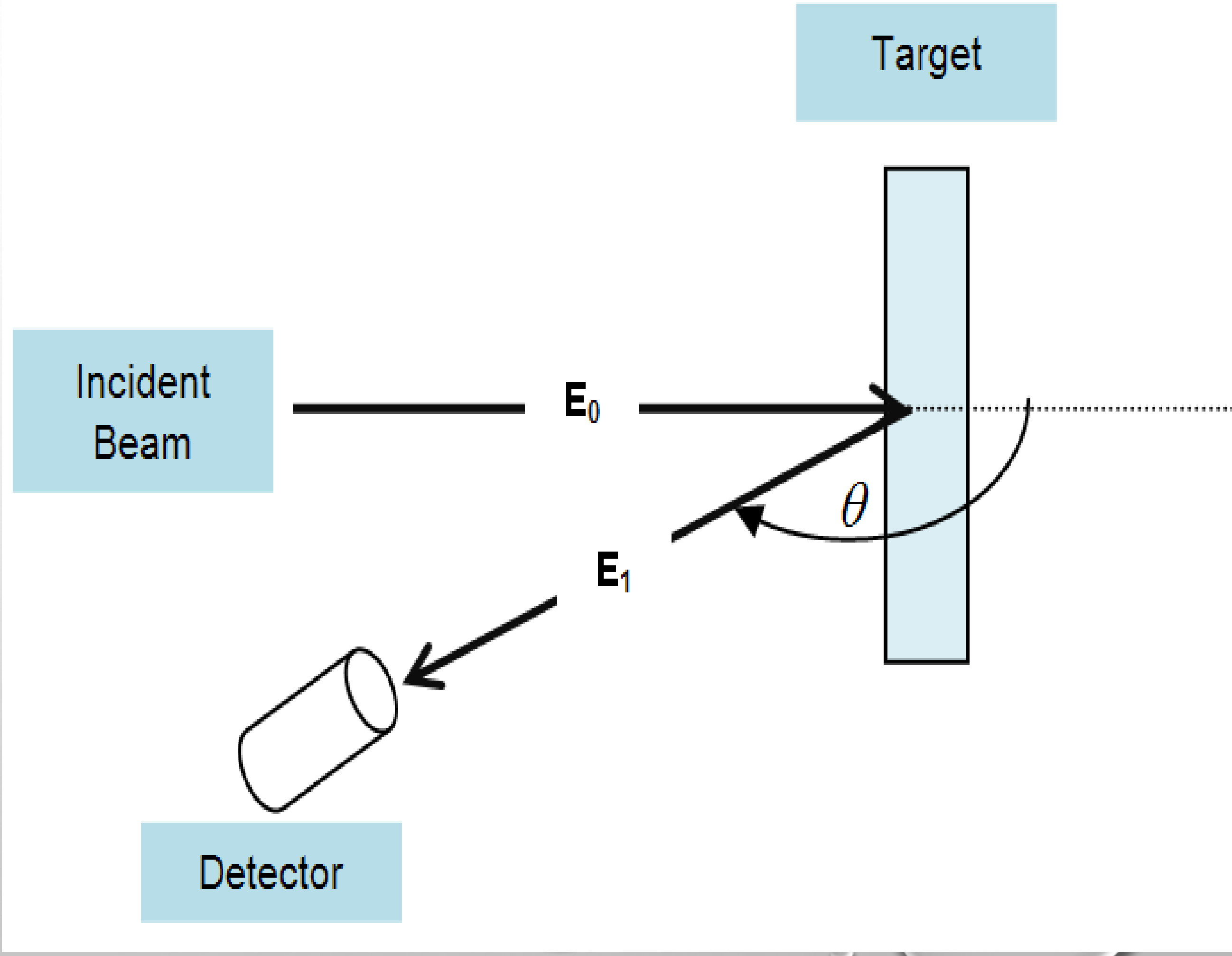
Rutherford Backscattering Spectrometry (RBS)

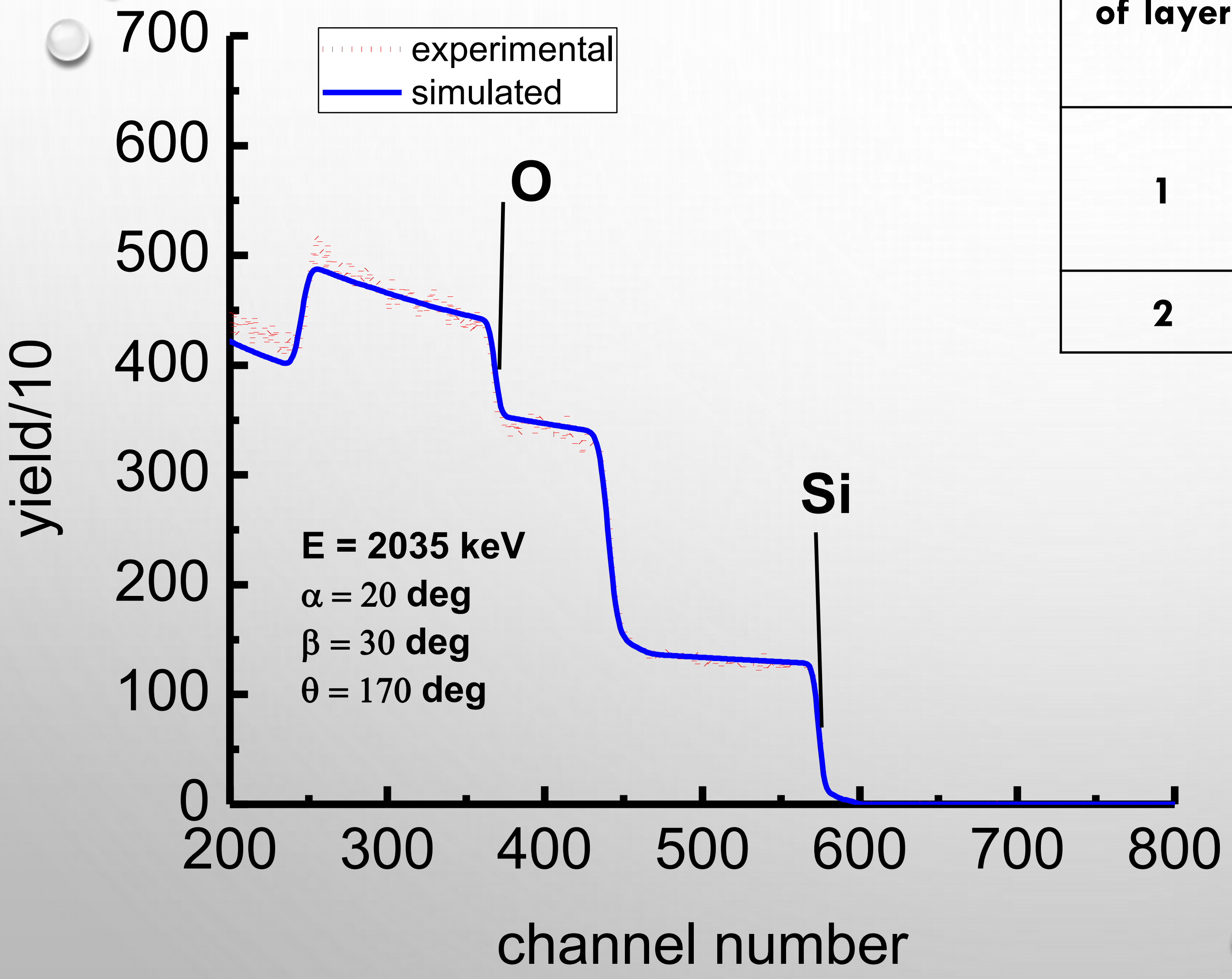
- The use of RBS is to provide information on concentration vs depth for different elements in a near surface layer samples.

- A beam of 2-3 MeV He^+ ions are directed at different angles on a sample surface.

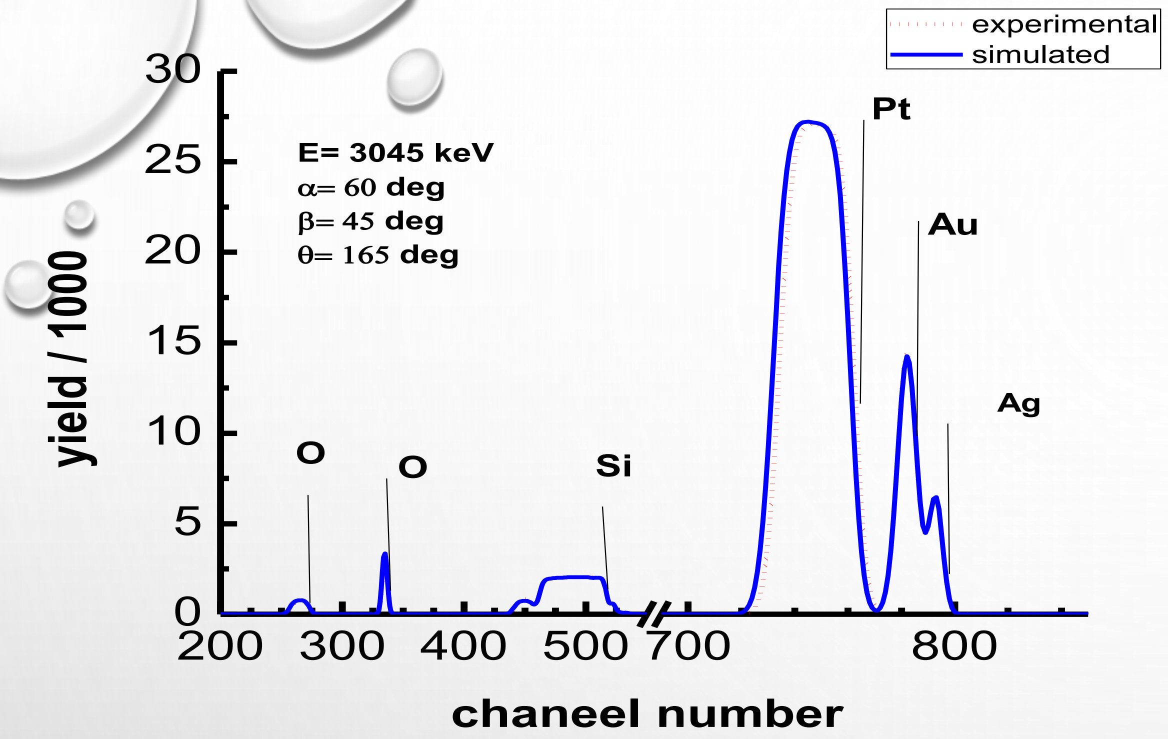
- The ion loses energy due to collision with electrons.

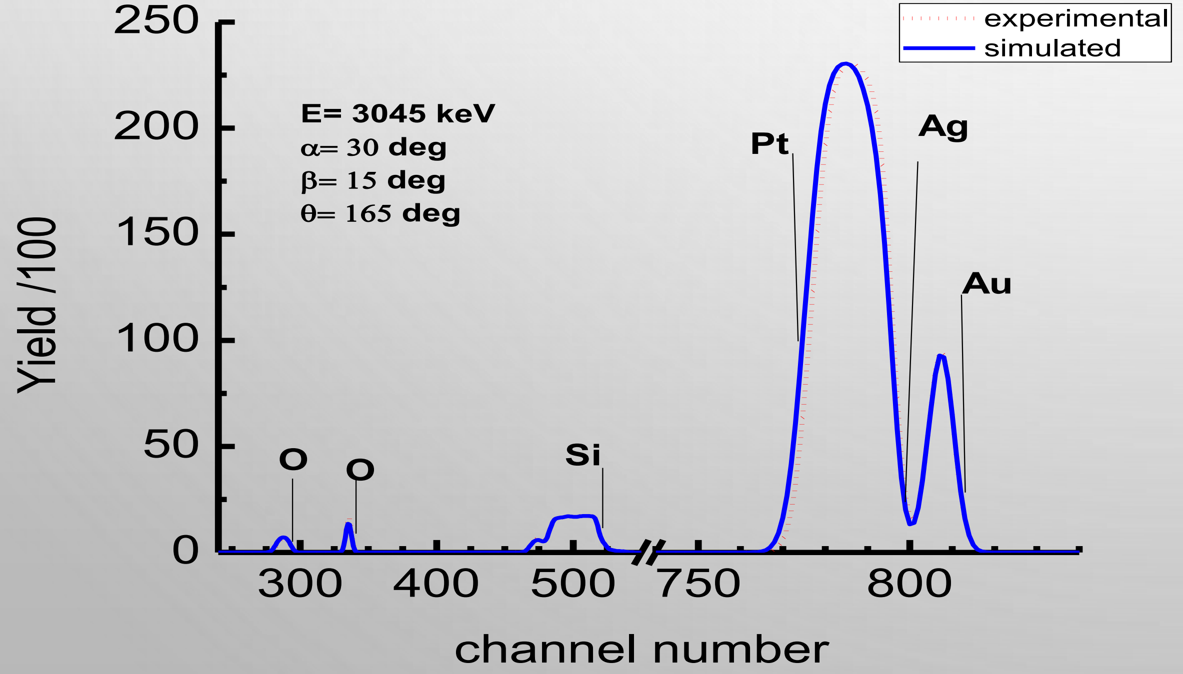
- The ion will scatter elastically with the atomic nucleus and lead to a kinematic factor K.





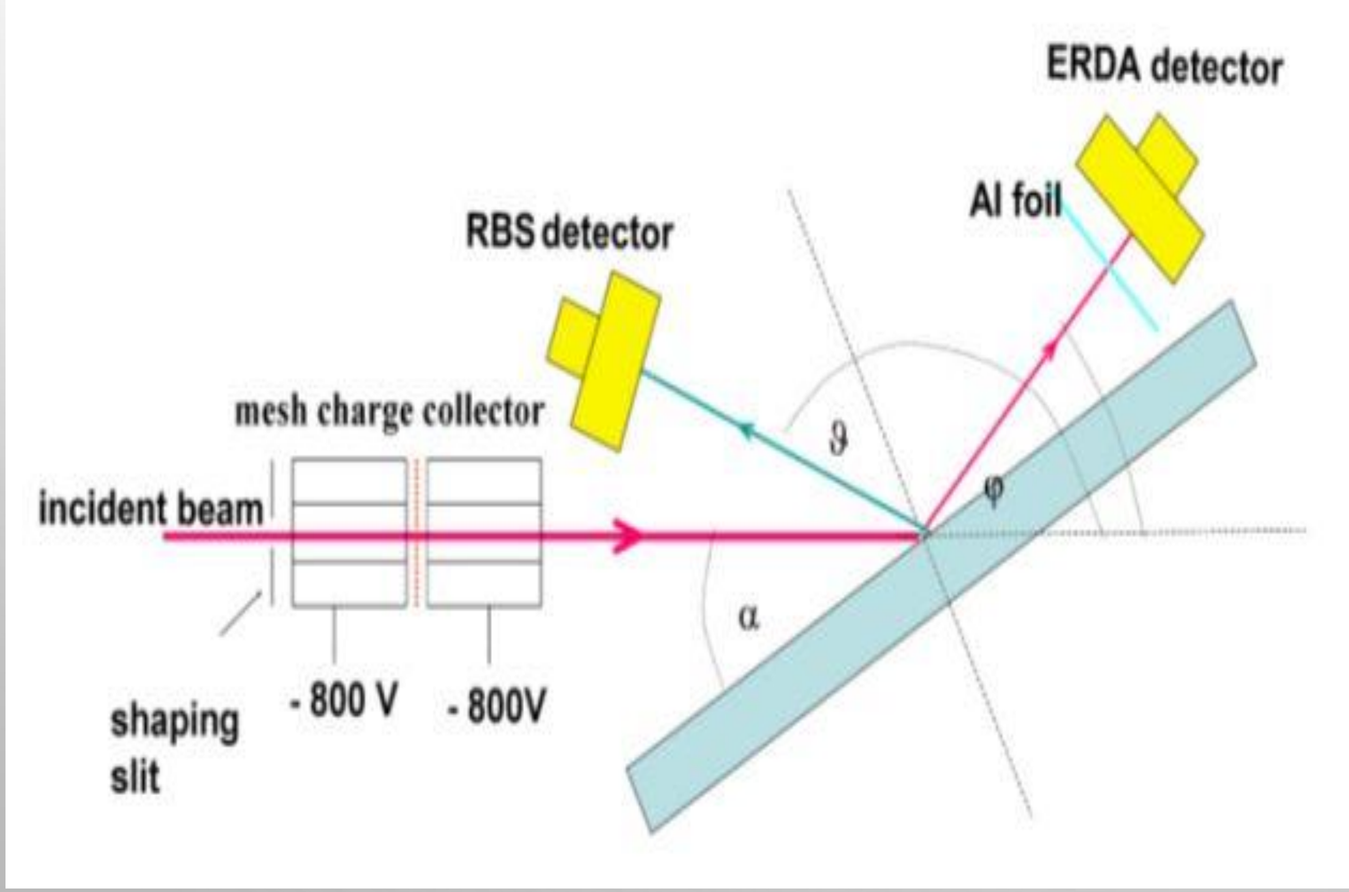
Number of layer	Name of element		Thickness (10^{15} atoms/cm^2)
	name	concentration	
1	Si	0.325	3330
	O	0.675	
2	Si	1.000	8500





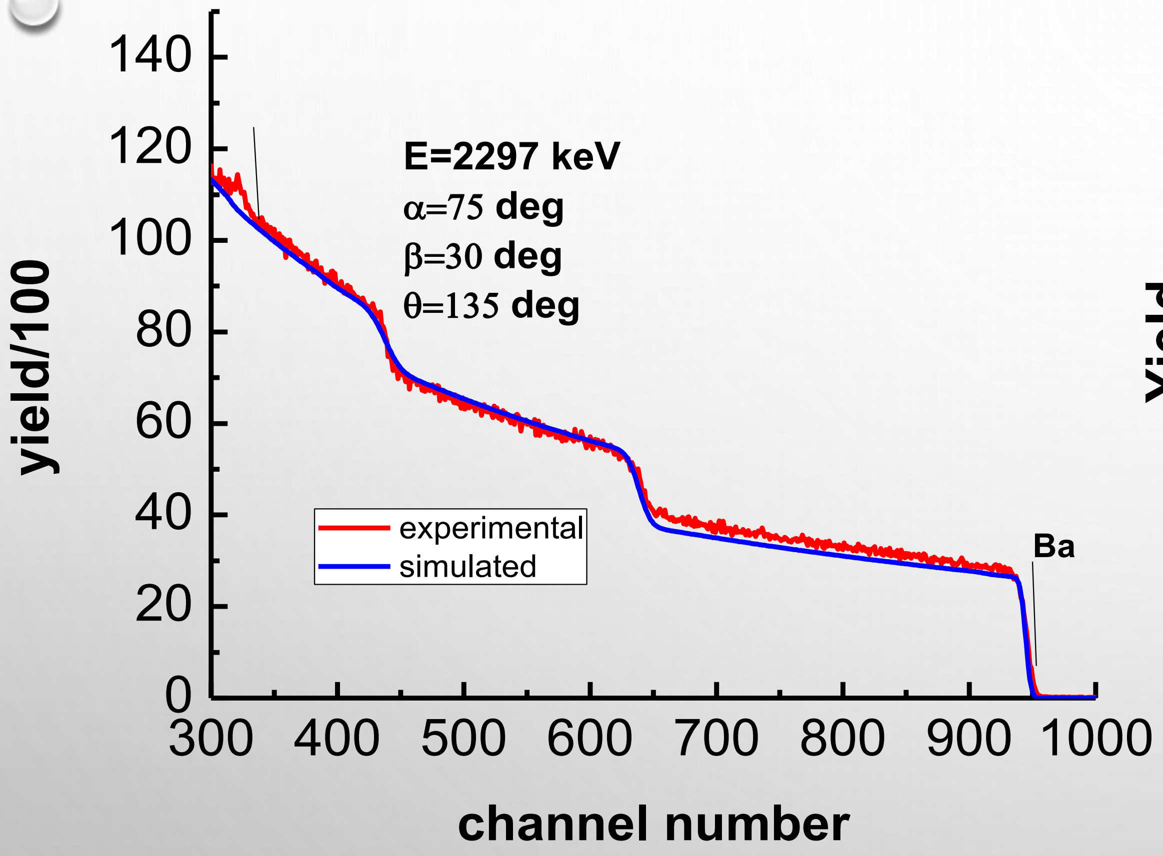
Number of layer	Name of element	concentration	Thickness 10^{15} atoms/cm^2
1	O	0.66	100
	Si	0.34	
2	Ag	1.00	50
3	Si	1.00	1500
4	Au	1.00	50
5	O	0.70	550
	Si	0.30	
6	Pt	1.00	300

Elastic Recoil Detection Analysis (ERDA)



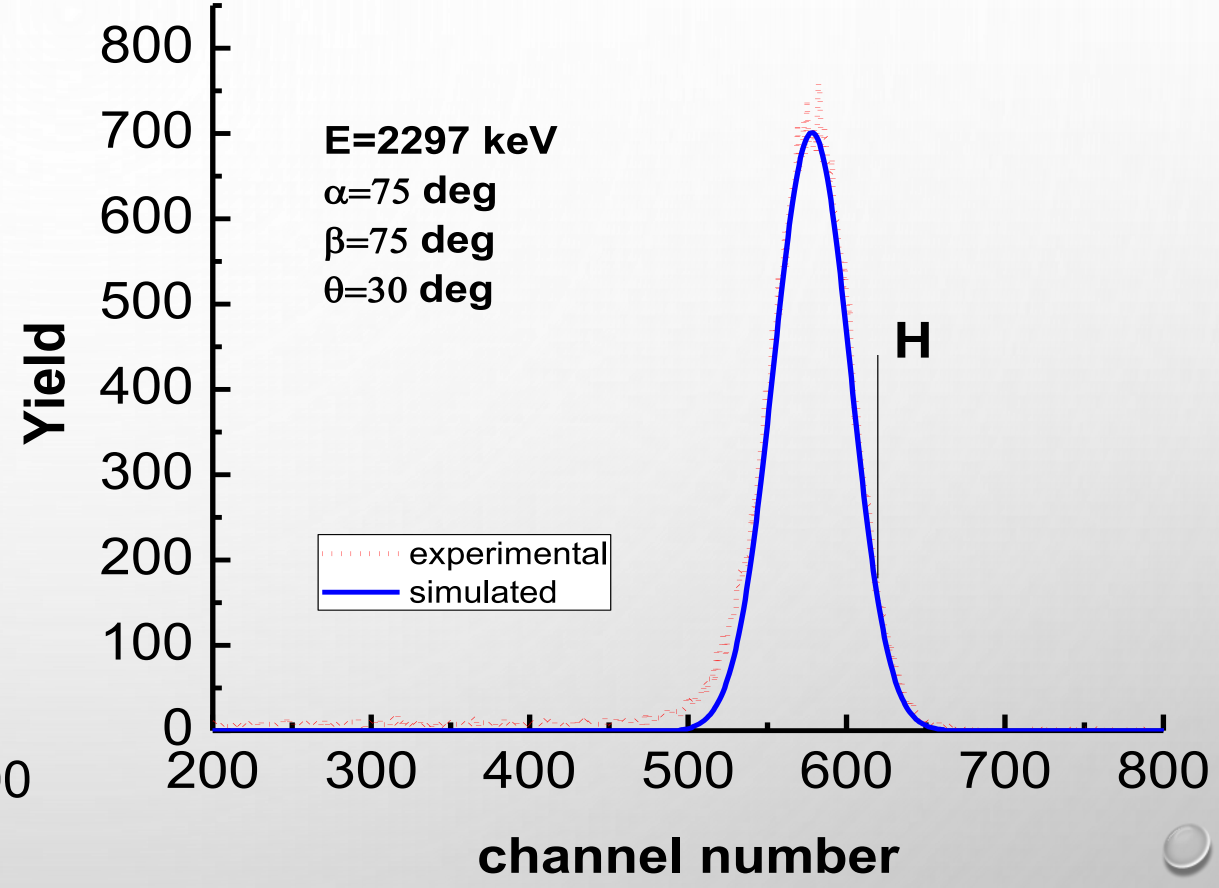
- He ions collide with a sample and atoms (H,D) are ejected from the sample.
- The incident energetic ions typically have MeV of energy, enough to kick out the atoms being struck.
- For ERD, the mass of the incident particle must be greater than that of the target nucleus.

RBS



140
120
100
80
60
40
20
0
yield/100
E=2297 keV
α=75 deg
β=30 deg
θ=135 deg
experimental
simulated
Ba
300
400
500
600
700
800
900
1000
channel number

ERDA



800
700
600
500
400
300
200
100
0
Yield
E=2297 keV
α=75 deg
β=75 deg
θ=30 deg
H
experimental
simulated
200
300
400
500
600
700
800
channel number

<table>
<tr><th rowspan="2">Number of layer</th><th colspan="5" rowspan="2">elements</th><th>Thickness</th></tr>
<tr><th>10^{15} atoms/cm^2</th></tr>
<tr><td rowspan="2">1</td><td>Name</td><td>H</td><td>C</td><td>Si</td><td>Ba</td><td rowspan="2">340</td></tr>
<tr><td>Concentration</td><td>0.125</td><td>0.614</td><td>0.01</td><td>0.25</td></tr>
<tr><td rowspan="2">2</td><td>Name</td><td colspan="2">C</td><td>Si</td><td>Ba</td><td rowspan="2">2350</td></tr>
<tr><td>Concentration</td><td colspan="2">0.709</td><td>0.01</td><td>0.28</td></tr>
<tr><td rowspan="2">3</td><td>Name</td><td>C</td><td colspan="2">Si</td><td>Ba</td><td rowspan="2">910</td></tr>
<tr><td>Concentration</td><td>0.25</td><td colspan="2">0.1</td><td>065</td></tr>
<tr><td rowspan="2">4</td><td>Name</td><td colspan="2">O</td><td colspan="2">Ba</td><td rowspan="2">8000</td></tr>
<tr><td>Concentration</td><td colspan="2">0.03</td><td colspan="2">0.97</td></tr>
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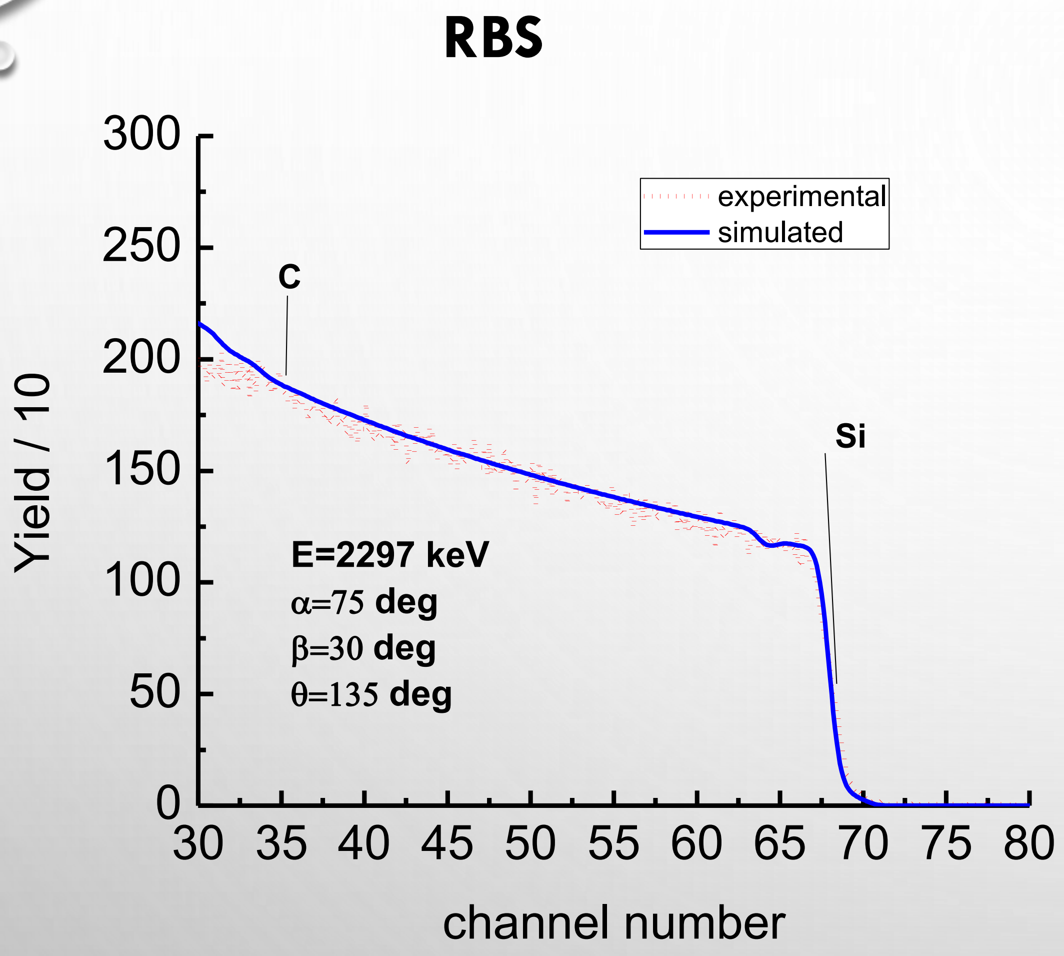
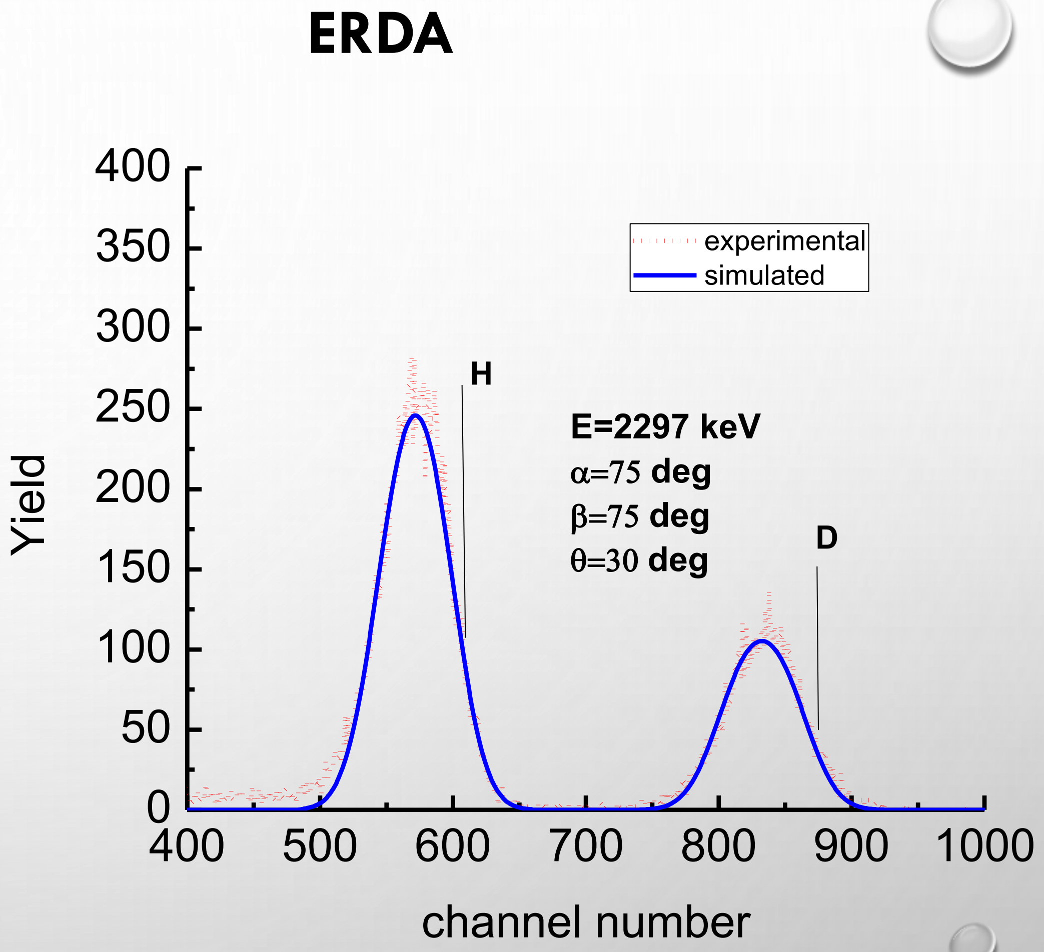

RBS
300
250
200
150
100
50
0
30 35 40 45 50 55 60 65 70 75 80
channel number
Yield / 10
experimental
simulated
C
Si
E=2297 keV
α=75 deg
β=30 deg
θ=135 deg


ERDA
400
350
300
250
200
150
100
50
0
400 500 600 700 800 900 1000
channel number
Yield
experimental
simulated
H
D
E=2297 keV
α=75 deg
β=75 deg
θ=30 deg

<table>
<tr><th rowspan="2">Number of layer</th><th rowspan="2" colspan="13">Name of element</th><th>Thickness</th></tr>
<tr><th>(10^{15} atoms/cm ^{2})</th></tr>
<tr><td rowspan="2">1</td><td>name</td><td colspan="3">H</td><td colspan="3">D</td><td colspan="3">C</td><td colspan="3">Si</td><td rowspan="2">700</td></tr>
<tr><td>concentration</td><td colspan="3">0.12</td><td colspan="3">0.30</td><td colspan="3">0.08</td><td colspan="3">0.50</td></tr>
<tr><td rowspan="2">2</td><td>name</td><td colspan="4">H</td><td colspan="4">C</td><td colspan="4">Si</td><td rowspan="2">50</td></tr>
<tr><td>concentration</td><td colspan="4">0.14</td><td colspan="4">0.36</td><td colspan="4">0.50</td></tr>
<tr><td rowspan="2">3</td><td>name</td><td colspan="6">C</td><td colspan="6">Si</td><td rowspan="2">20000</td></tr>
<tr><td>concentration</td><td colspan="6">0.25</td><td colspan="6">0.75</td></tr>
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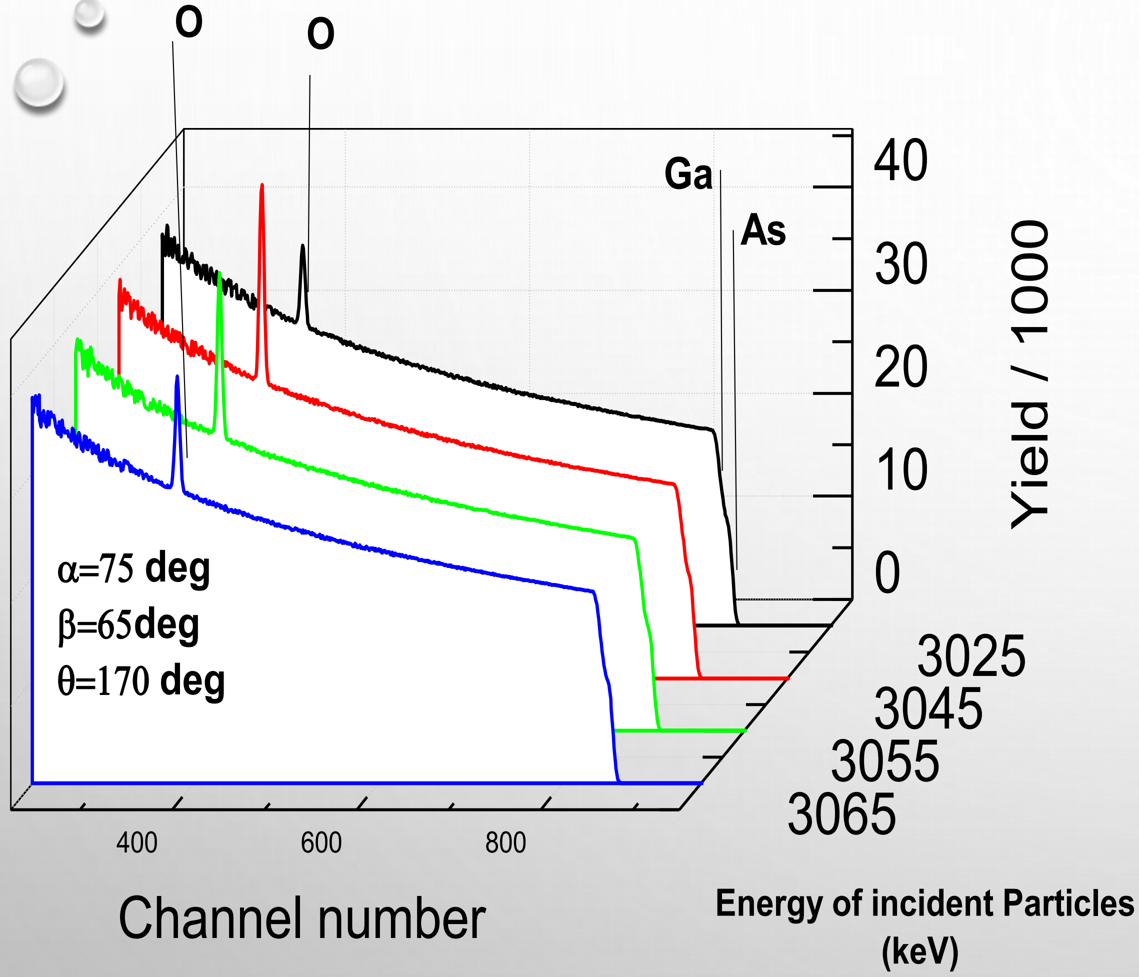
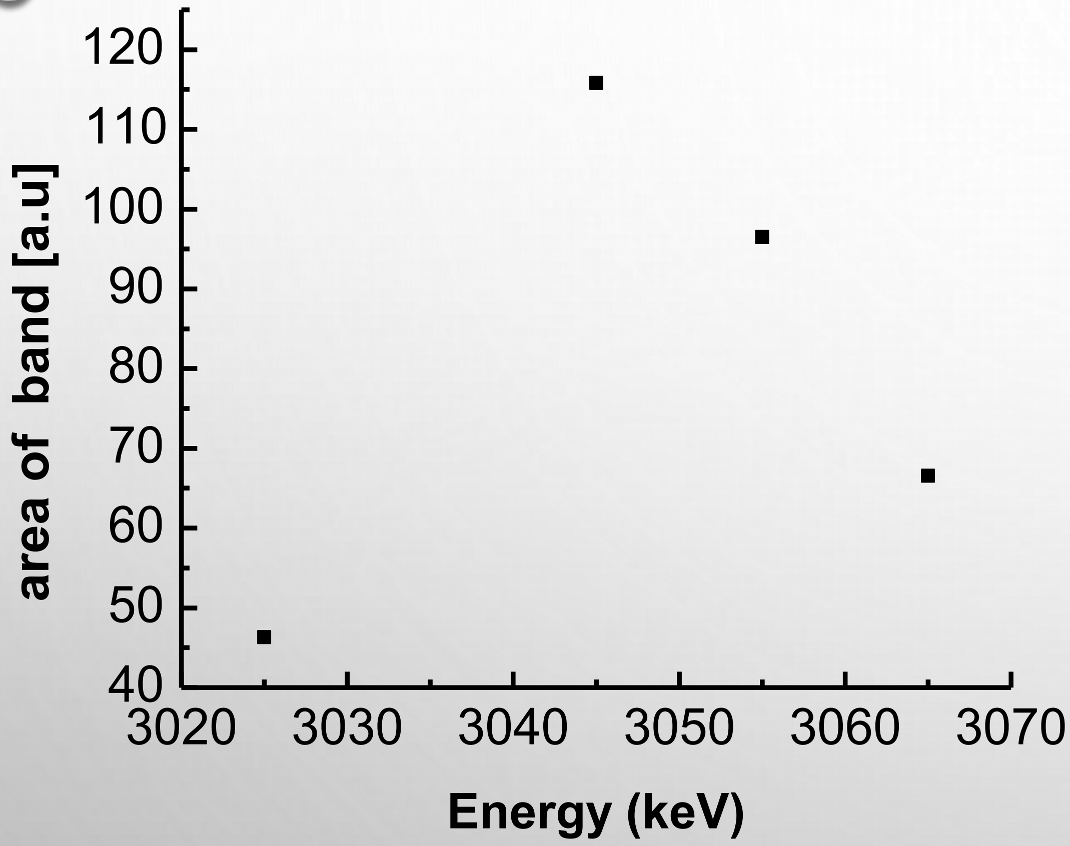


Number of layer	elements				Thickness (10^{15} atoms/cm^2)	Thickness nm
1	name	O	Ga	As	5.5	1.2
	Concentration	0.8	0.1	0.1		
2	name	Ga		As	6000	
	Concentration	0.5		0.5		



Energy [keV]	area of band [a.u.]
3065	66575
3055	96482
3044	115831
3025	46296

Conclusion

- These methods are non-destructive techniques to study materials

- The used methods allow the determination of depth distribution and concentration from hydrogen to heavy elements.

- The spectra calculations and model comparisons was executed in SIMNRA software tool, in which good agreement was achieved for RBS and ERD experiments.

- Furthermore, the depth resolution is done near to few nm range for these methods.

- The sensitivity for heavy elements is of the order 10^{14} atoms/cm^2

THANK YOU