Development of NRA System for a 1.7 MV Tandem Accelerator

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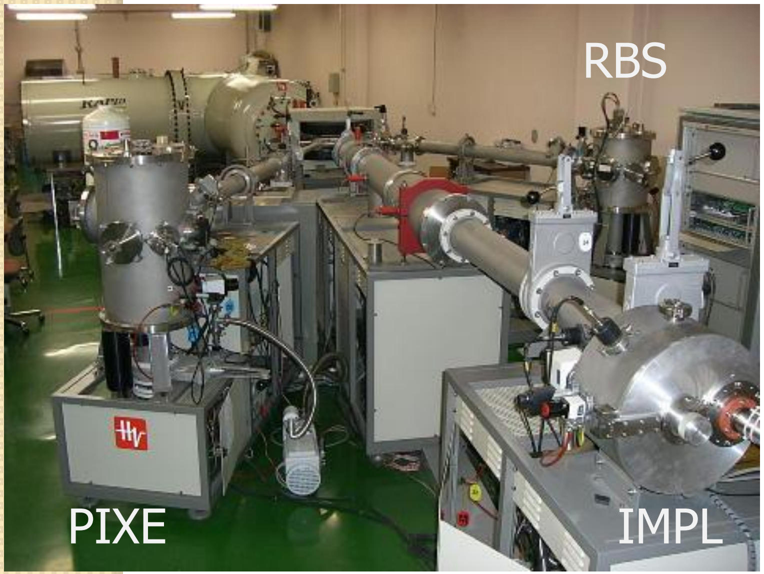
Specification of RAPID



Main usage so far:

Ion Implantation

RBS (Rutherford Backscattering Spectroscopy)

PIXE (Particle Induced X-ray)

Potentially:

Channeling, N-RBS, ERDA and NRA

Specification

Negative ion Sources

Cs sputtering Type:

Extraction Voltage 20kV

Duoplasmatron Type:

Extraction Voltage 20kV

Accelerator

Available voltage range: 0.1-1.7MV

Stability: < 30 Vrms

Produced beam current

H^{+} : 25μA (3.4 MeV)

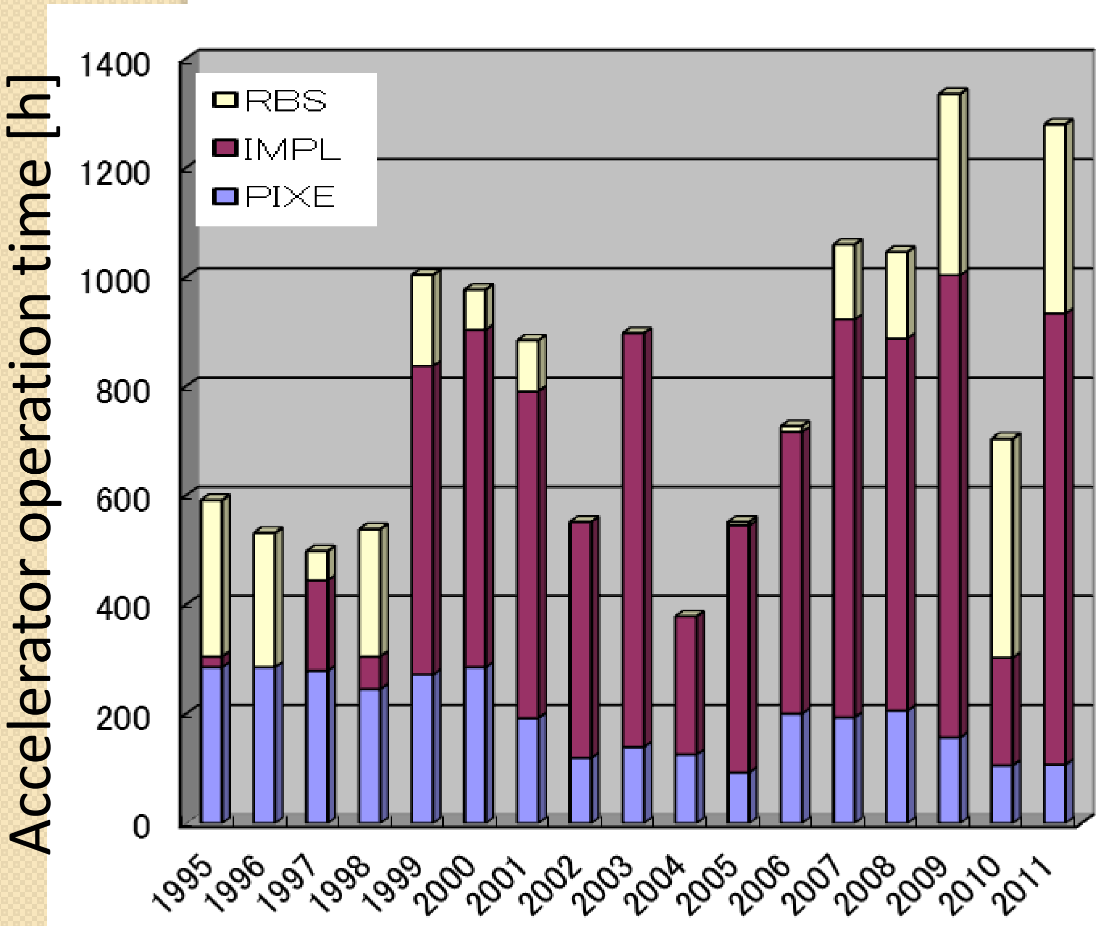
He^{2+} : 2.0μA (5.1 MeV)

Si^{2+} : 140μA (5.1 MeV)

Au^{2+} : 60μA (5.1 MeV)

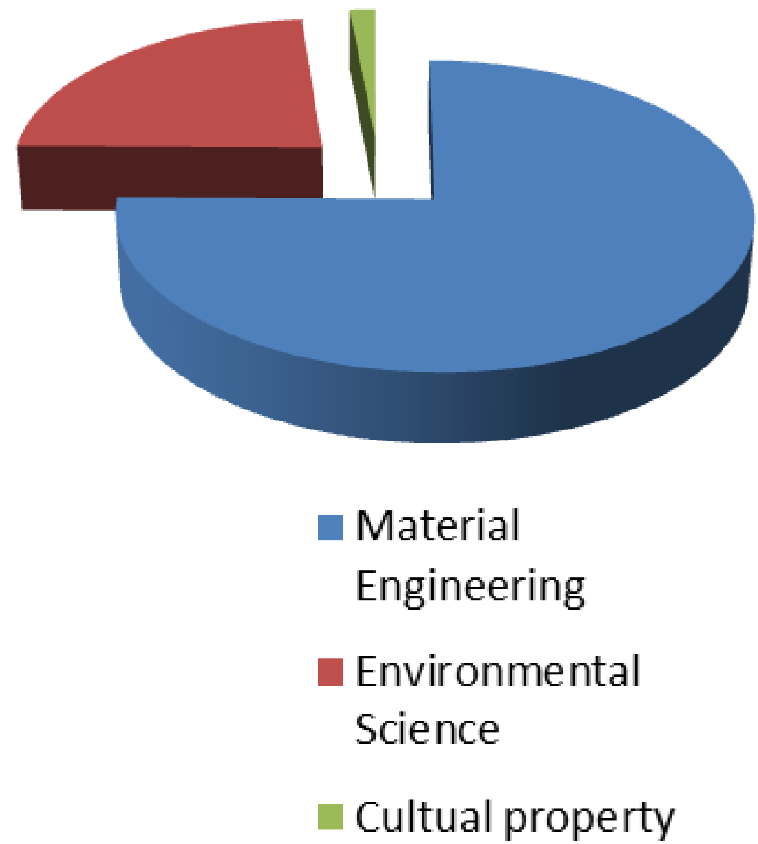
Accelerator operation time since the installation

Accelerator operation



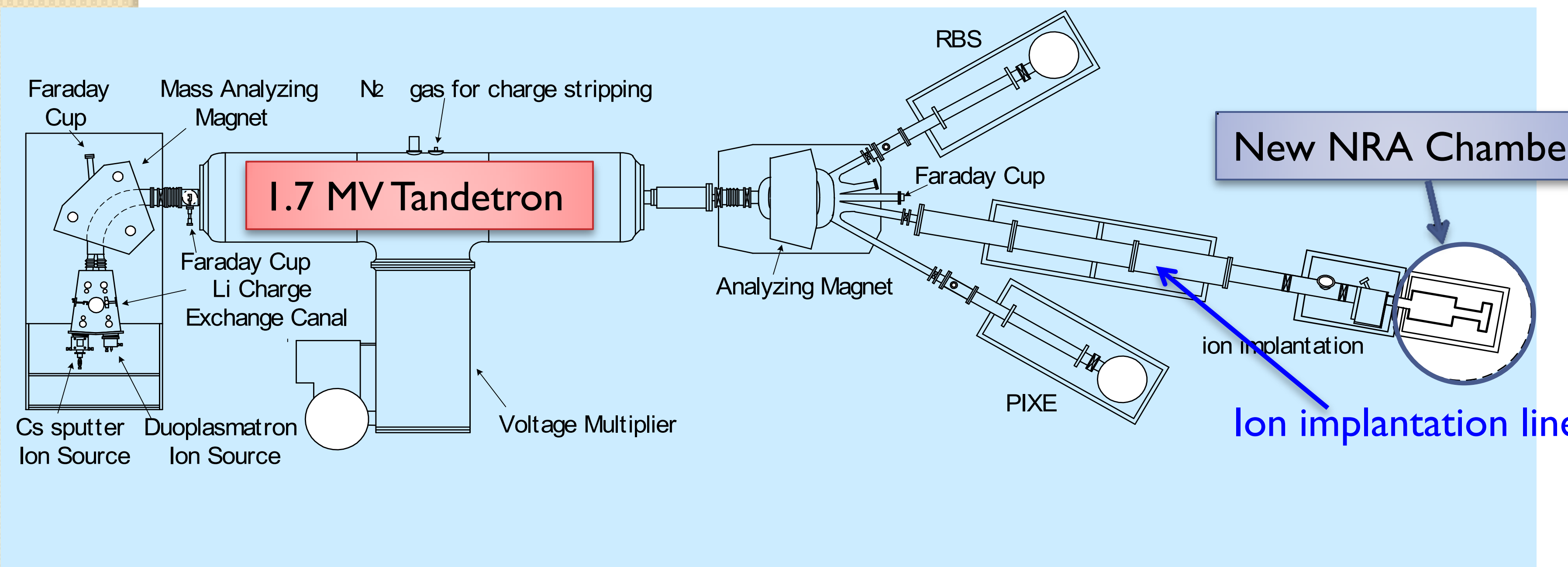
Fiscal years 1994 to 2011

Research Field



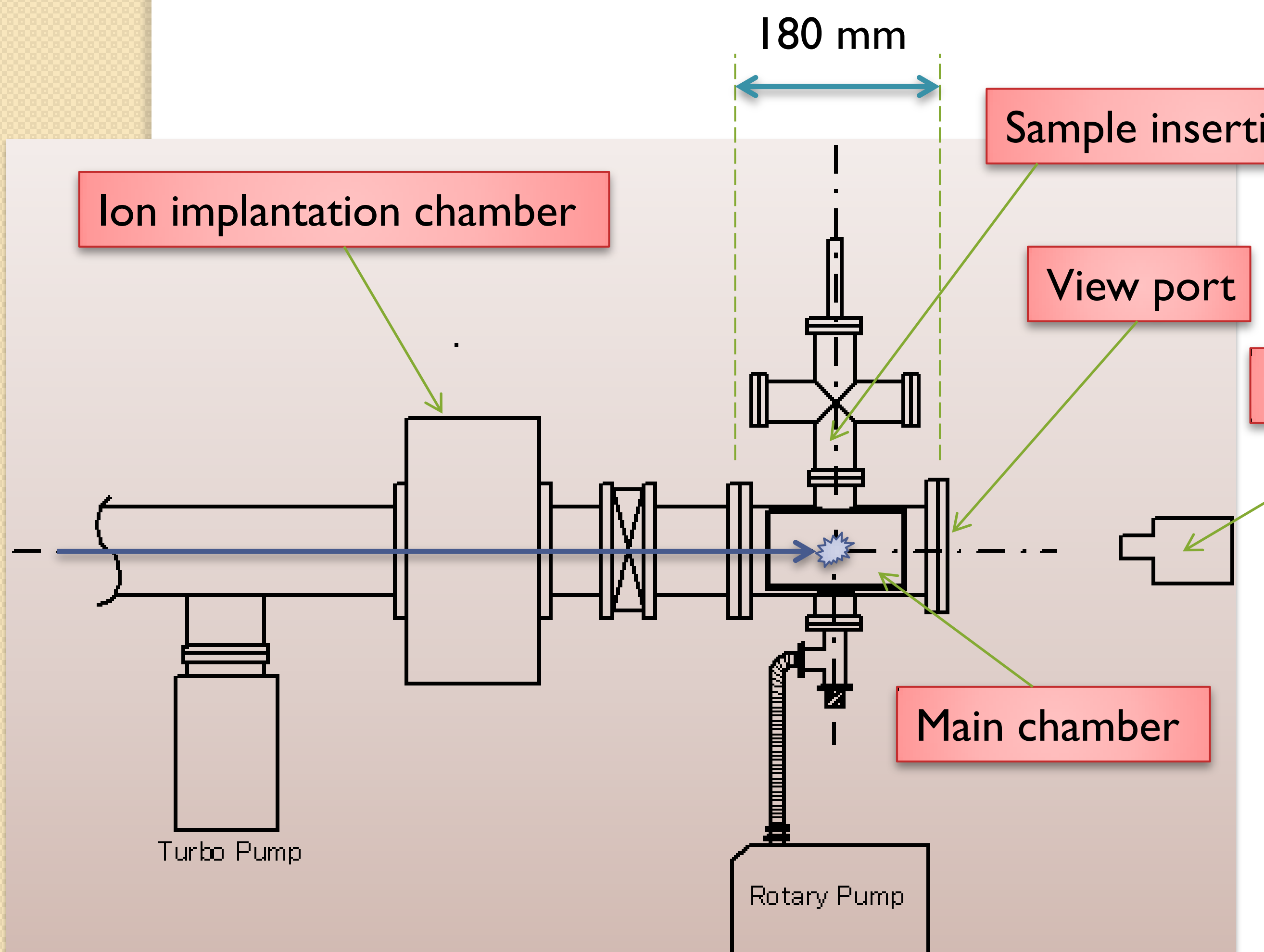
New NRA System

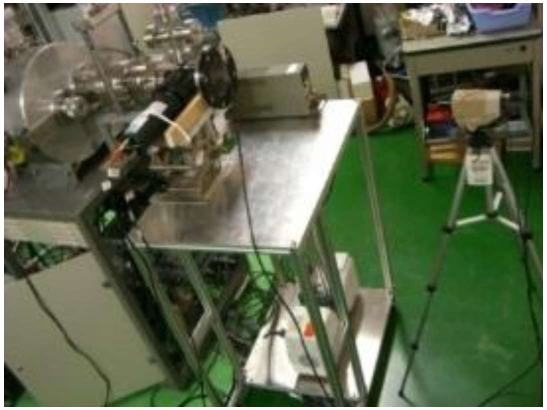
To respond recent demand for the sensitive quantification of light elements (H, N, O, F, etc.), NRA detection system was newly developed at the end of the ion implantation line.



Outlook of New NRA System

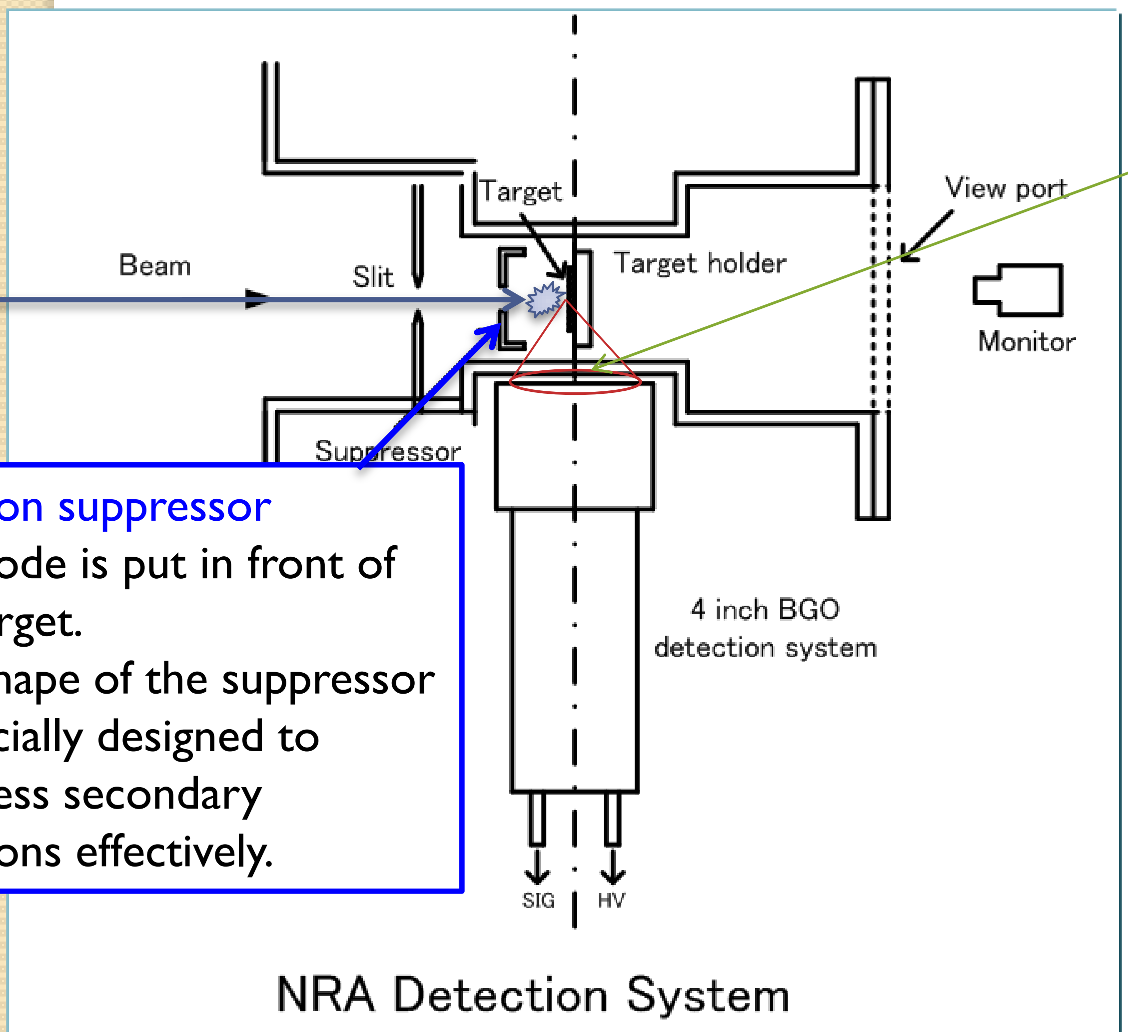
The new NRA chamber is connected to the end port of the ion implantation chamber. It consists of the main chamber and the sample insertion port.





Main chamber

Top view of the main chamber. The special feature is a deeply scooped duct to make the BGO detector being close to the reaction position.

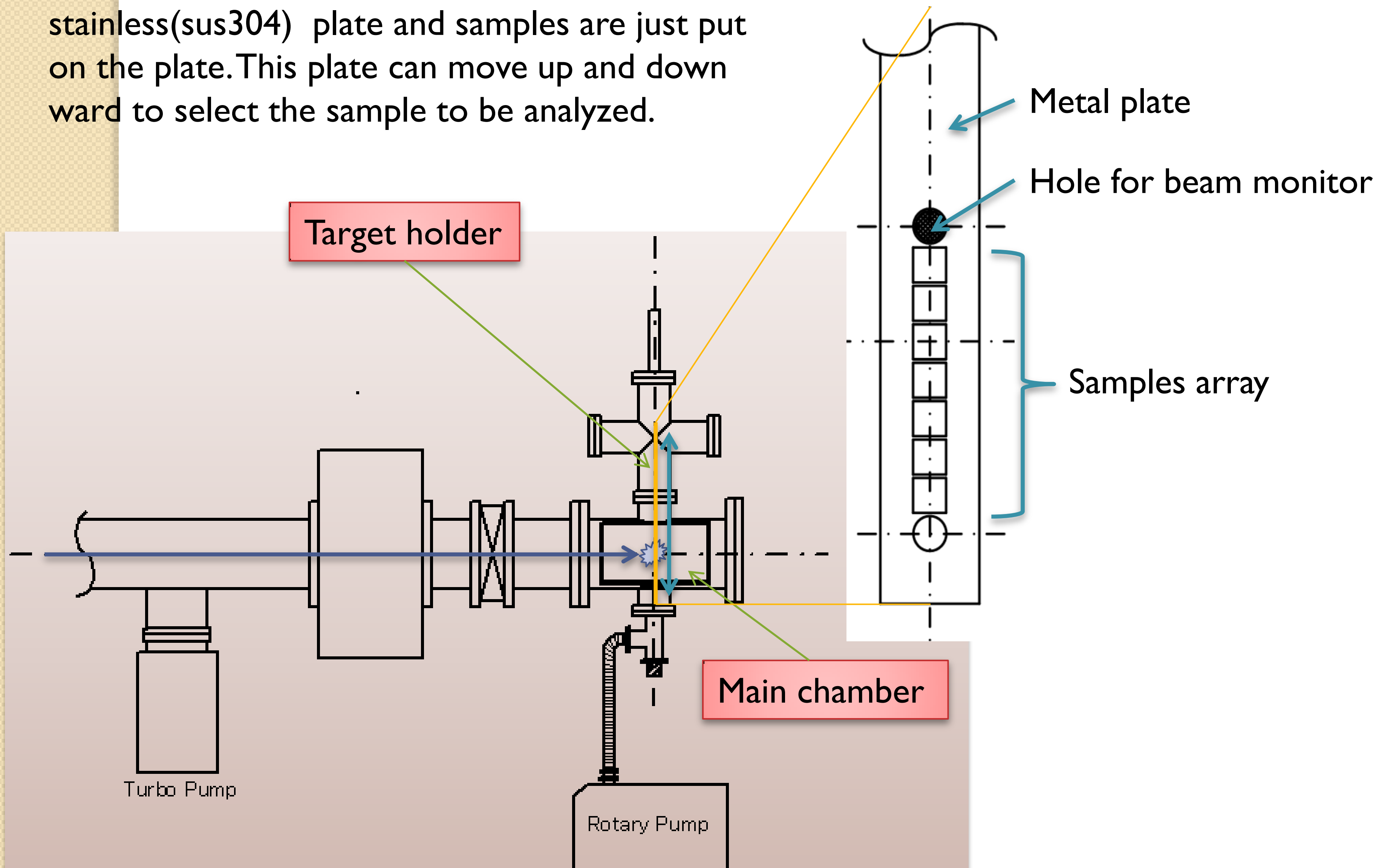


By this design, Large effective solid angle for the detector is realized.

Electron suppressor electrode is put in front of the target.
The shape of the suppressor is specially designed to suppress secondary electrons effectively.

Target holder

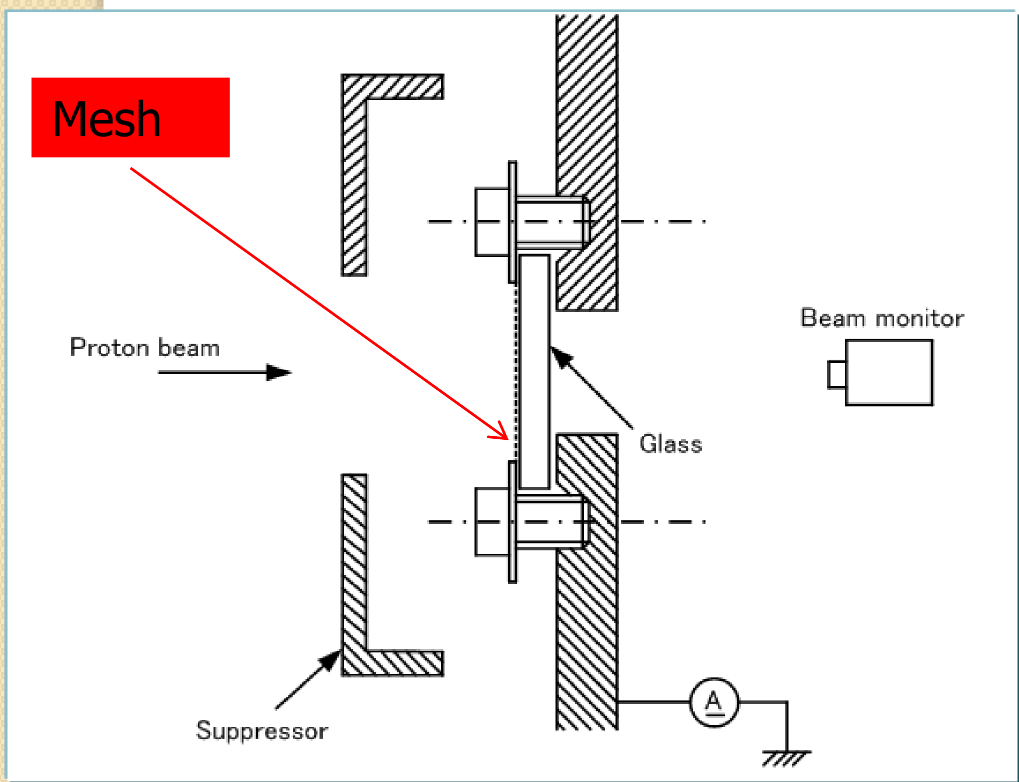
Close-up of the target holder. It is made of metal stainless(sus304) plate and samples are just put on the plate. This plate can move up and down ward to select the sample to be analyzed.



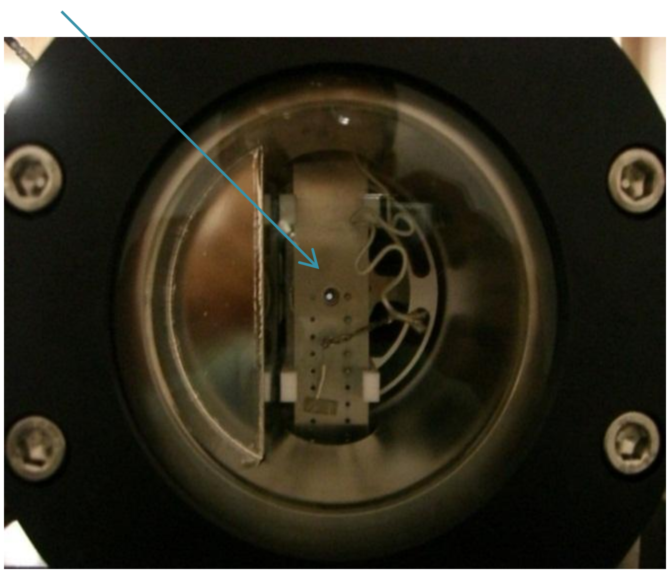
Beam monitor system

A glass plate is put at the beam monitor position (a hole on the target holder metal plate) to make the beam monitor. The glass is lit by the beam and this light can be observed by a video camera set the end of the main port.

A fine copper mesh (opening 98%) is set in front of the glass to avoid charge-up.



Observation of proton beam

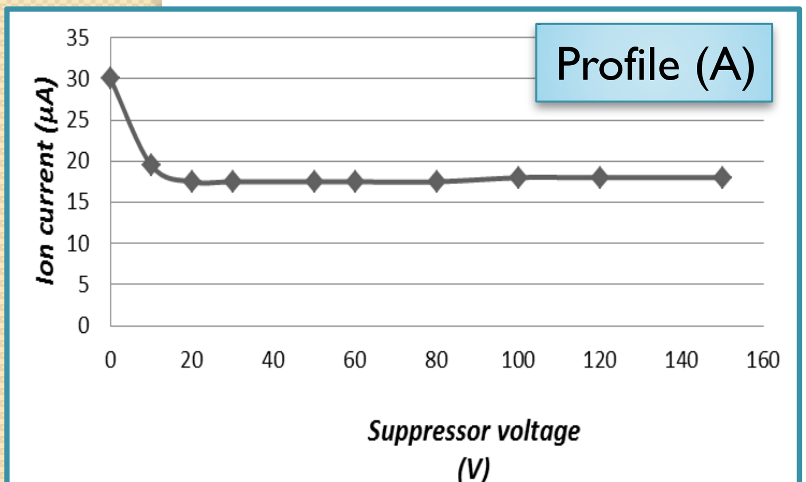


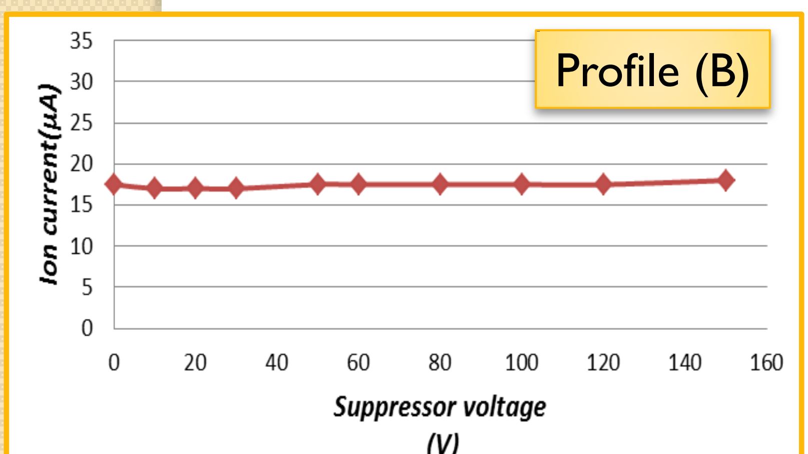
The effect of the copper mesh

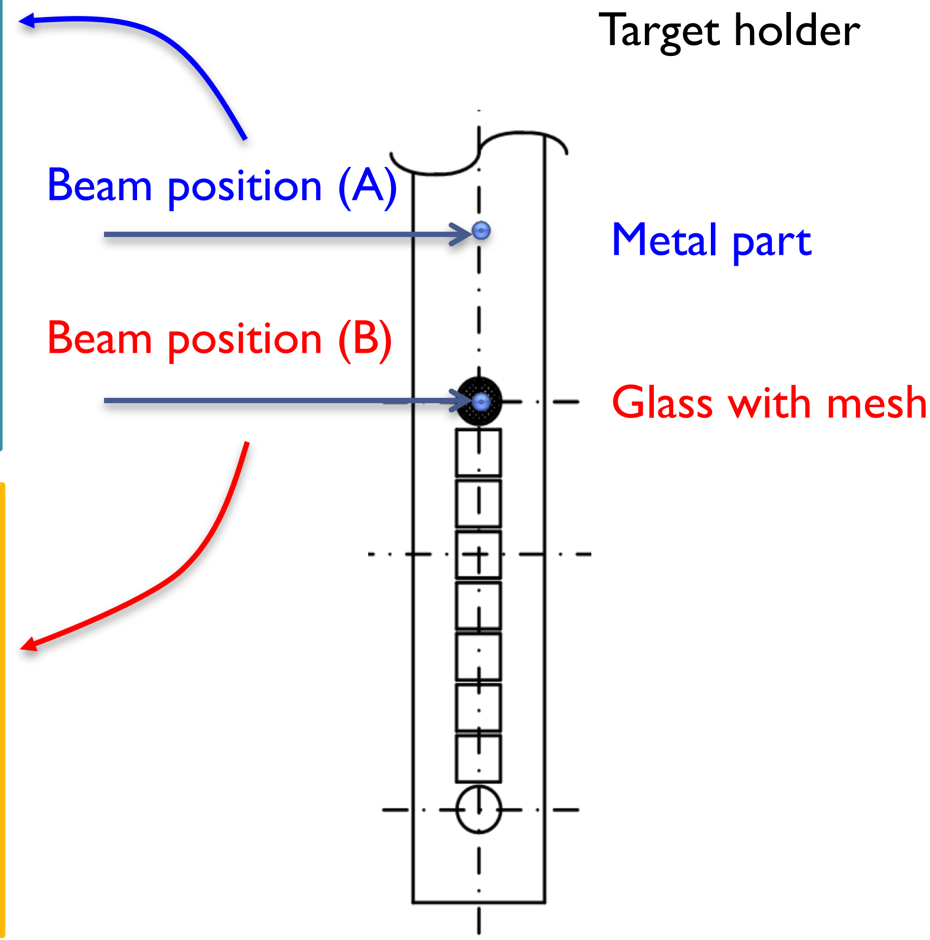
Comparison of observed ion current profiles with respect to the suppressor voltage:

(A) Beam is at the position of the metal plate

(B) Beam is at the beam monitor position (glass with mesh)





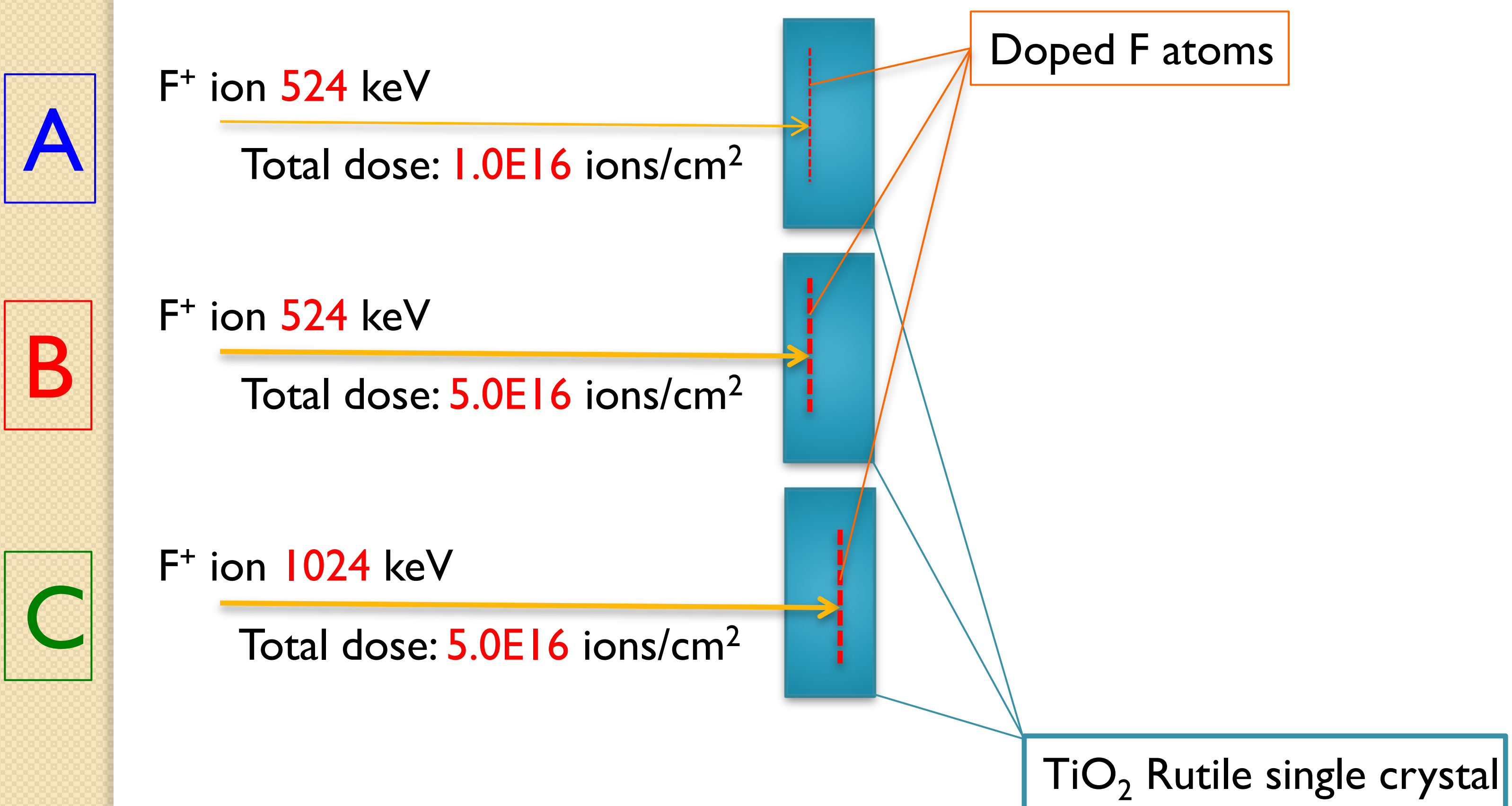


→ The mesh acts not only as charge-up suppressor but also as an electron suppressor!

Demonstration of newly developed NRA system

The NRA experiments were demonstrated using $^{19}F(p,\alpha\gamma)^{16}O$ reaction. The experiment was to obtain the Fluorine depth profiles at the surface of TiO_2 substrate. The targets were prepared by F^+ ion implantation.

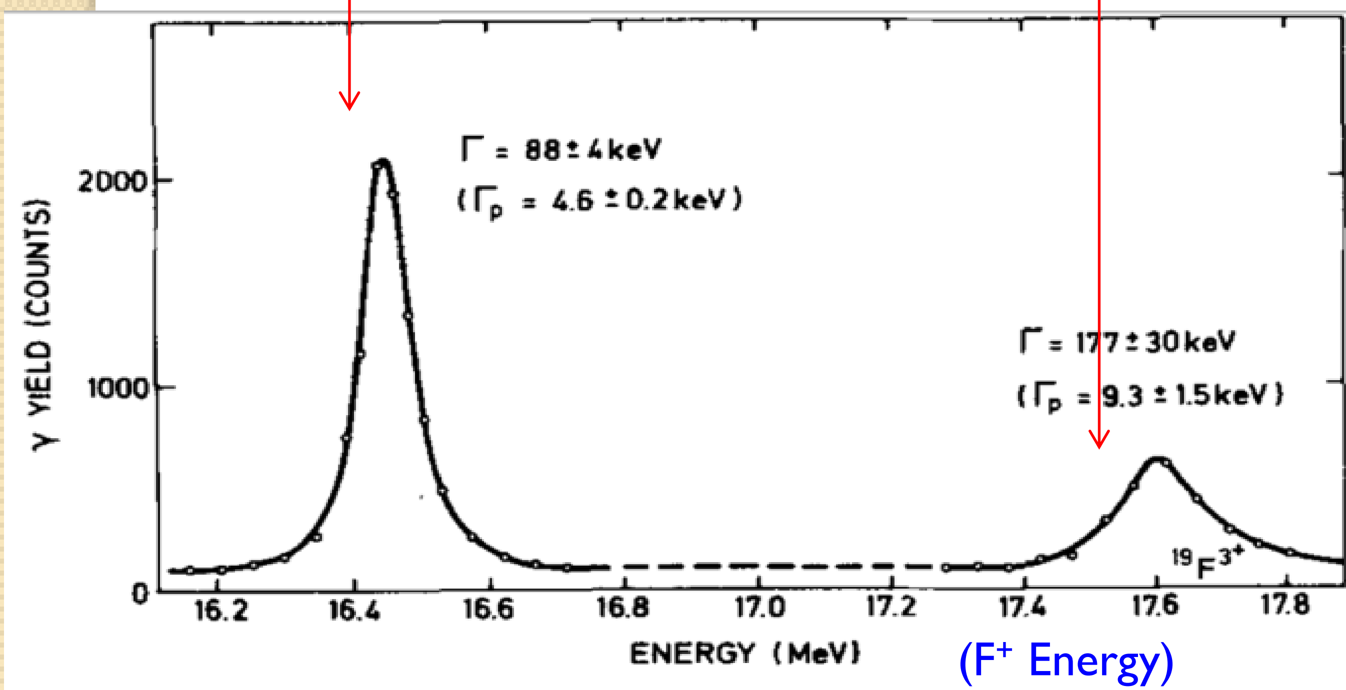
Target samples preparation: 3 conditions



The $^{19}F(p, \alpha\gamma)^{16}O$ reaction

The 1st resonance (16.44MeV)
(proton energy = 872keV)

The 2nd resonance (17.5MeV)
(proton energy = 935keV)

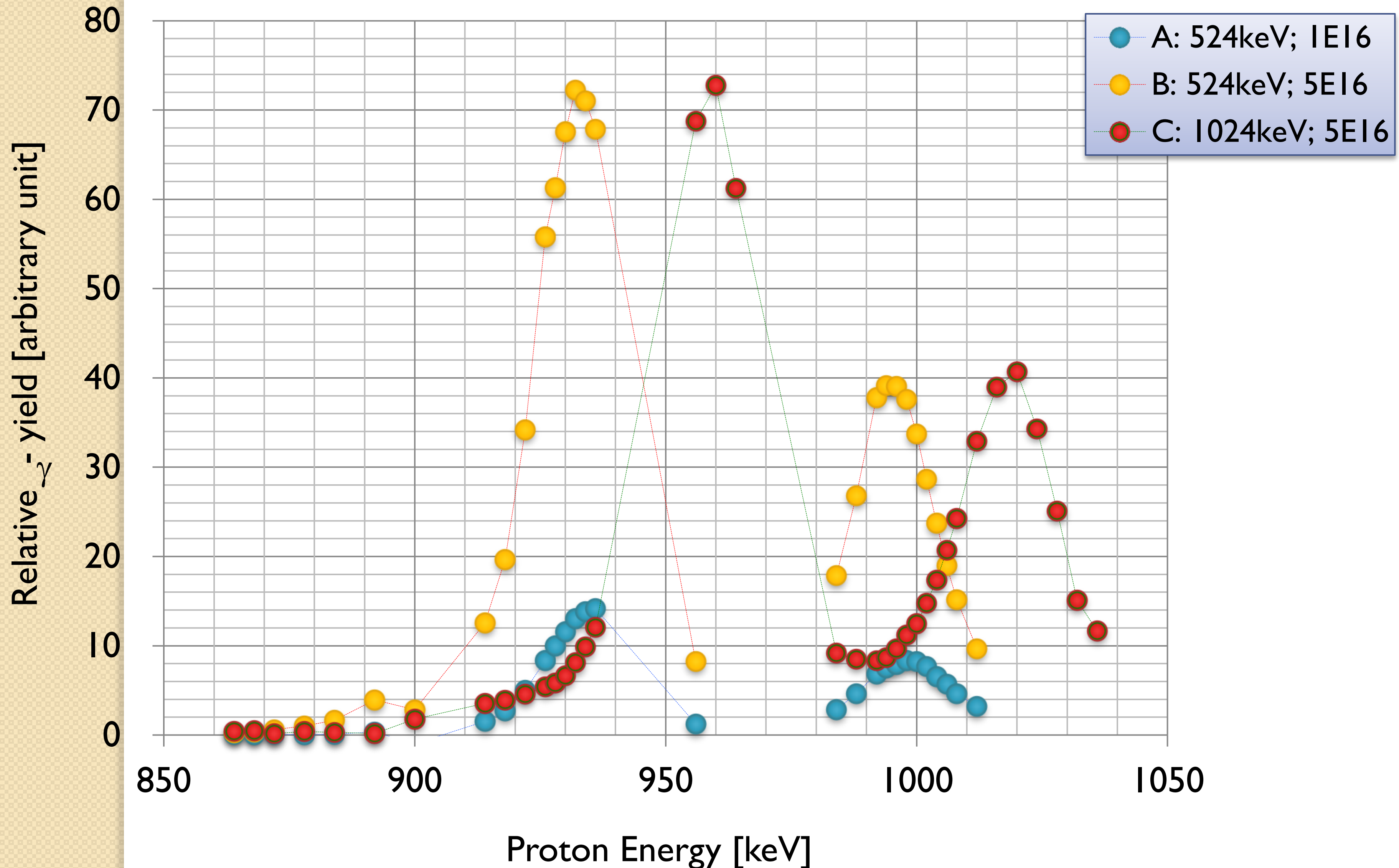


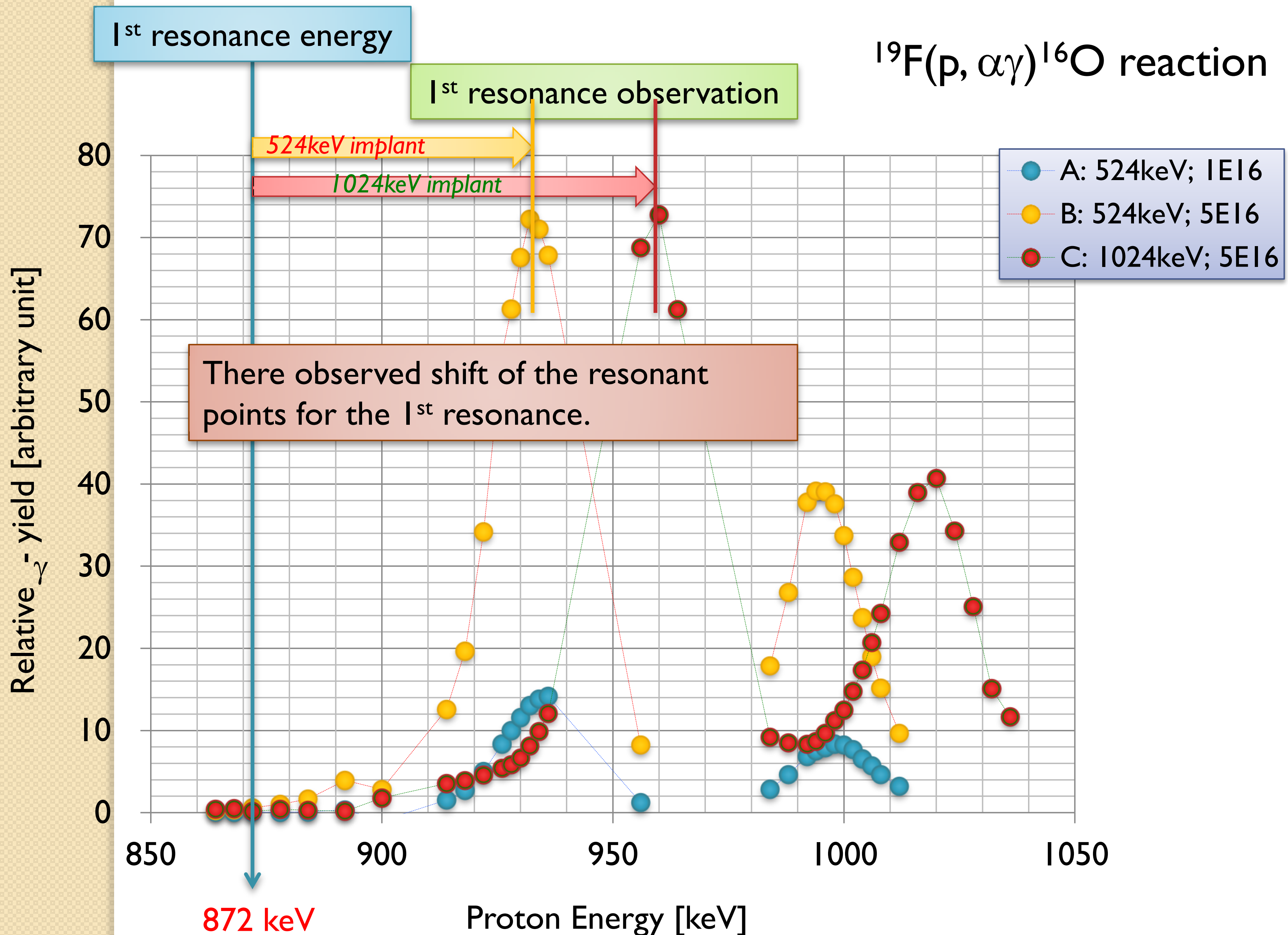
J. Bottiger, et al.(1976)
j. Appl. Phys. 47.
1672-1605

Proton energy	Reaction	Gmma-ray energy	Cross section
(keV)		(MeV)	(mb)
872	$^{19}F(p,\alpha\gamma)^{16}O$	7.12, 6.92, 6.13	540
935	$^{19}F(p,\alpha\gamma)^{16}O$	7.12, 6.92, 6.13	180

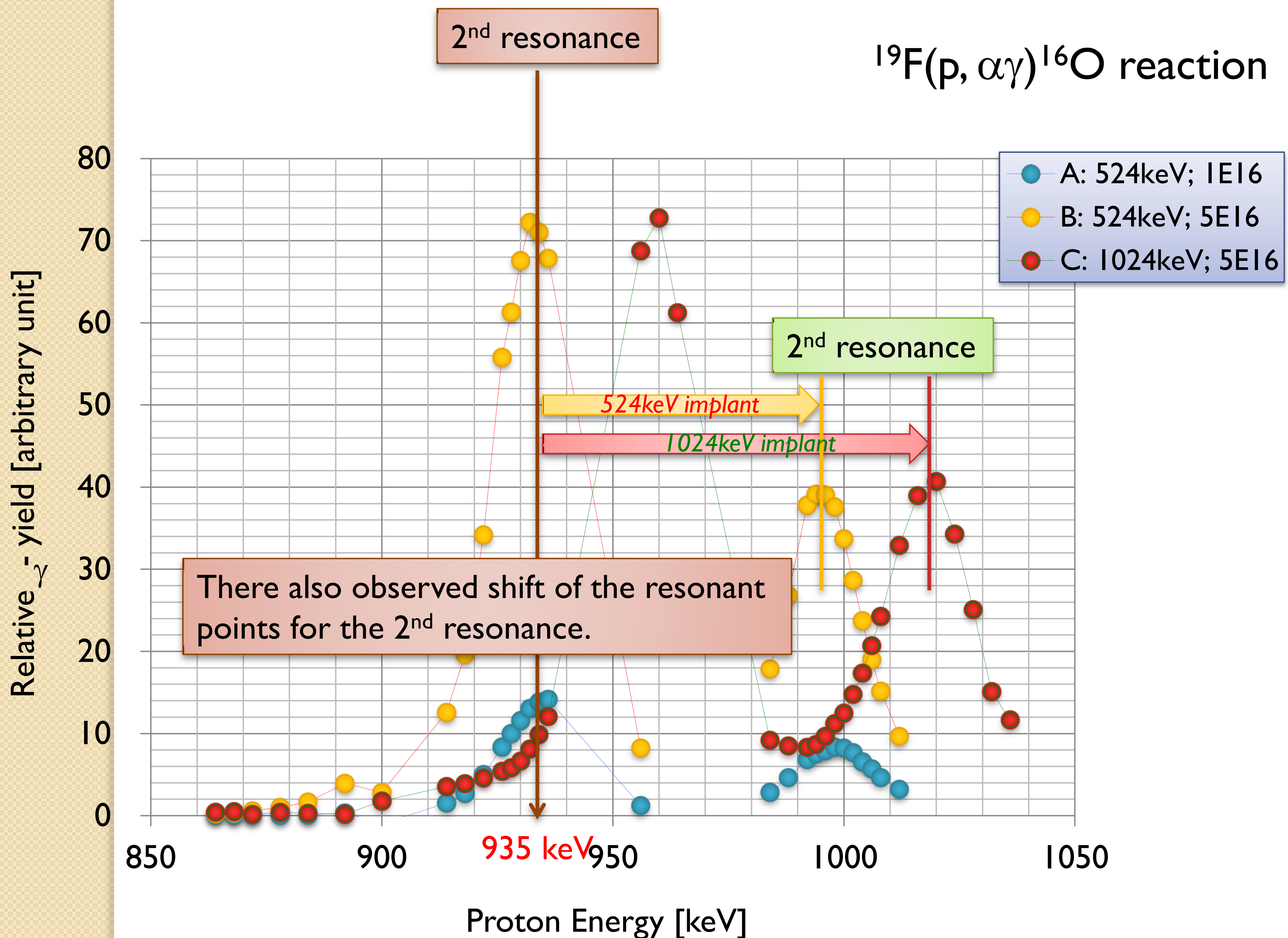
Experimental results

$^{19}F(p, \alpha\gamma)^{16}O$ reaction





1st resonance energy
$^{19}F(p, \alpha\gamma)^{16}O$ reaction
1st resonance observation
524keV implant
1024keV implant
A: 524keV; 1E16
B: 524keV; 5E16
C: 1024keV; 5E16
There observed shift of the resonant points for the 1st resonance.
Relative γ - yield [arbitrary unit]
80
70
60
50
40
30
20
10
0
850
900
950
1000
1050
872 keV
Proton Energy [keV]



2nd resonance
19F(p, αγ)16O reaction
A: 524keV; 1E16
B: 524keV; 5E16
C: 1024keV; 5E16
2nd resonance
524keV implant
1024keV implant
There also observed shift of the resonant points for the 2nd resonance.
Relative γ - yield [arbitrary unit]
80
70
60
50
40
30
20
10
0
850
900
935 keV
950
1000
1050
Proton Energy [keV]

Summary of the observation

From the observation, positions (depths) of F ion doped were estimated as following.
The estimations from 1st resonance data and 2nd resonance data are consistent with each other.
The F ions doped with 524 keV was estimated to be at 810 – 840 nm depth.
The F ions doped with 1024 keV was estimated to be around at 1185 nm depth.

Observation

	1st resonance	872 keV			Average Energy Loss*		Equivalent Depth
B	(524keV)	932 keV	$\Delta=$	60 keV	(932 -> 872)	74.2 keV/μm	809 nm
C	(1024keV)	959 keV	$\Delta=$	87 keV	(959 -> 872)	73.6 keV/μm	1182 nm
	2nd resonance	935 keV			Average Energy Loss*		Equivalent depth
B	(524keV)	995 keV	$\Delta=$	60 keV	(995 -> 935)	71.3 keV/μm	841 nm
C	(1024keV)	1019 keV	$\Delta=$	84 keV	(1019 -> 935)	70.8 keV/μm	1187 nm

*Energy loss data are estimated by SLIM2008.

Student experiment program

The demonstrated experimental set up was applied to the student experiment program for the master course of the department of Nuclear Engineering.
The results were very simple and helpful to understand the interaction between ions – target or ions – materials, thus very educational.

Preparation

Measurement

Analysis

Summary

- A NRA (Nuclear Reaction Analysis) system was developed at the RAPID accelerator facility, The University of Tokyo to meet sensitive quantification of light elements.

- The NRA system has several features:
  1) Chamber design for high counting efficiency.
  2) Effective electron suppression.
  3) Effective avoidance against charge-up by using fine copper mesh.

- Especially, we found that the mesh acts not only as charge-up inhibitor but also as an electron suppressor. This indicates a possibility for the sophisticated sample holder without additional electron suppressor electrode.

- The NRA experiments using $^{19}F(p,\alpha\gamma)^{16}O$ reaction were successfully demonstrated. Since the results were clear, this experimental setup was applied to the student experiment program.

- The newly developed NRA system has great potential for the frontier research for the materials science and functional material process engineering.