MEASUREMENT OF THE ^{11}B TARGET THICKNESS BY USING THE ELASTIC SCATTERINGS WITH PROTON PARTICLES OF 1.1 - 1.9 MeV ENERGY

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Outline

I. Motivation and overview

II. Experimental setup

III. Results and discussion

IV. Conclusions

Motivations

- Thickness of target is an essential information to determine absolute cross sections

M.Munch et al., EPJ/A,56,17,2020

- The formula of the differential cross section reaction:

$$\boxed{\frac{d\sigma}{d\Omega} = \frac{Y}{N_t \cdot N_p \cdot \Delta\Omega}} \qquad (1)$$

Where Y - the number of scattered particles and corresponds to the experimental yield,

N_t – the number of target nucleus, proportional to the target thickness

N_p - the number of the incident beam particles,

$\Delta\Omega$ - the solid angle subtended by the detector located at the angle θ_{lab}

Target thickness measurement techniques

- ***Measurement the energy loss of the charged particle in the target:***
  - Widely used to measure target thickness
  - But insensitive to the elemental composition of the target
  - And requires the knowledge of the stopping power of the material

K. Ramavataram, D.I. Porat, Nucl. Instr. and Meth. 4 (1959) 239
V.E. Lewis, Nucl. Instr. and Meth. 64 (1968) 293.

- ***Measurement of the width of resonance from the yield of gamma-ray:***
  - Applicable only to a selected class of nuclei

C. Pruneau *et al.*, Can. J. Phys. **63** (1985) 1141

- ***Measurement of the elastically scattered light projectiles***
  - Requires the knowledge of the elastic scattering cross section.

R.K. Jolly and H.B. White, Jr., Nucl. Instr. and Meth. 97 (1971) 299.
B.L. Cohen and R.A. Moyer, Anal. Chem. 43 (1971) 123.

Elastic scattering method

- The thickness of target (gram per cm^2) is calculated as:

$$\boxed{d = \frac{N_t . M_A}{N_A} = \frac{Y \cdot M_A}{\frac{d\sigma}{d\Omega} \cdot N_p \cdot \Delta\Omega \cdot N_A}}$$

where N_t is the number of target nucleus, M_A is the molecular weight of the target element, Y is the experimental yield, $\frac{d\sigma}{d\Omega}$ is the cross section, $\Delta\Omega$ - the solid angle, N_A is the Avogadro constant.

→ ***If $\frac{d\sigma}{d\Omega}$ is known, the thickness d is determined***

R.K. Jolly, H.B. White,
Nucl. Instr. and Meth., **97**(2), 1971, 299-307.

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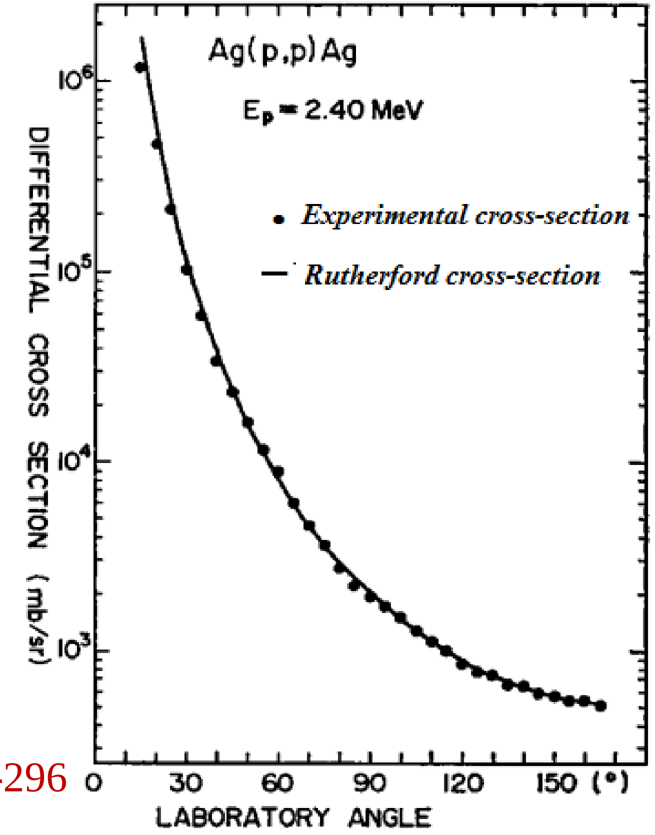
1/ For heavy targets, at low beam energy, the Rutherford backscattering is used to determine thickness



S. Kato, NIM **75** (1969) 293-296

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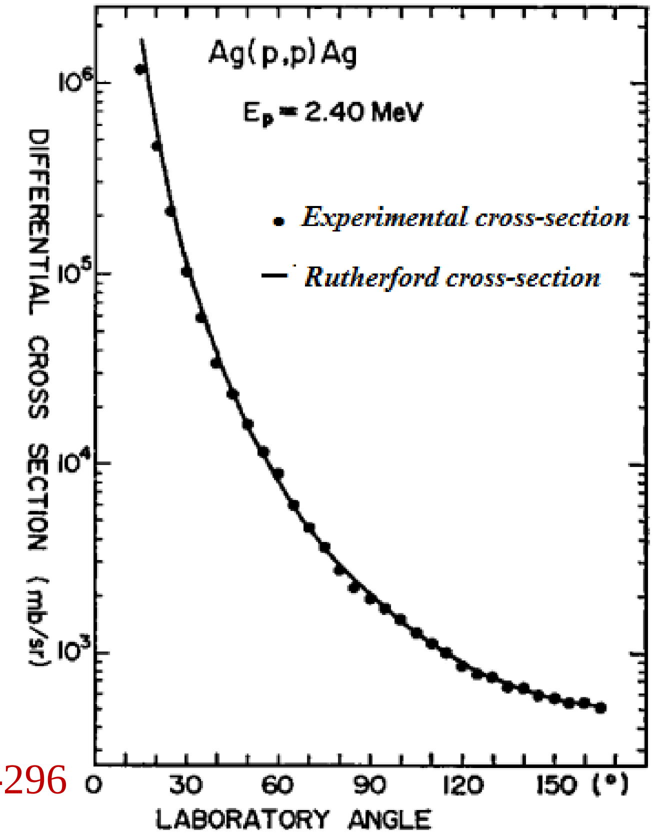
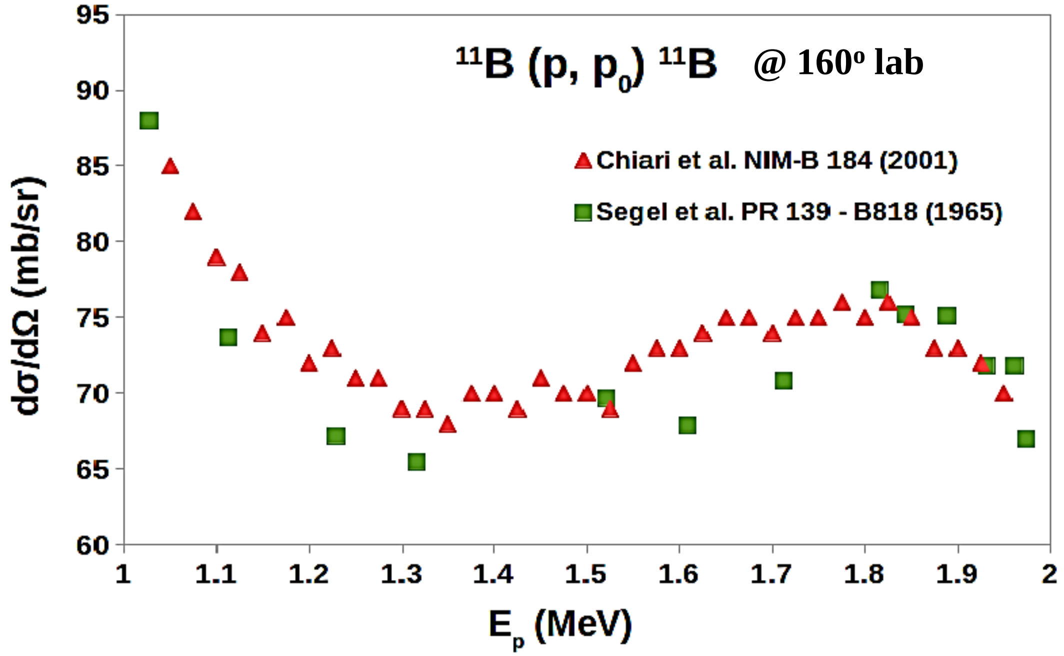


S. Kato, NIM **75** (1969) 293-296

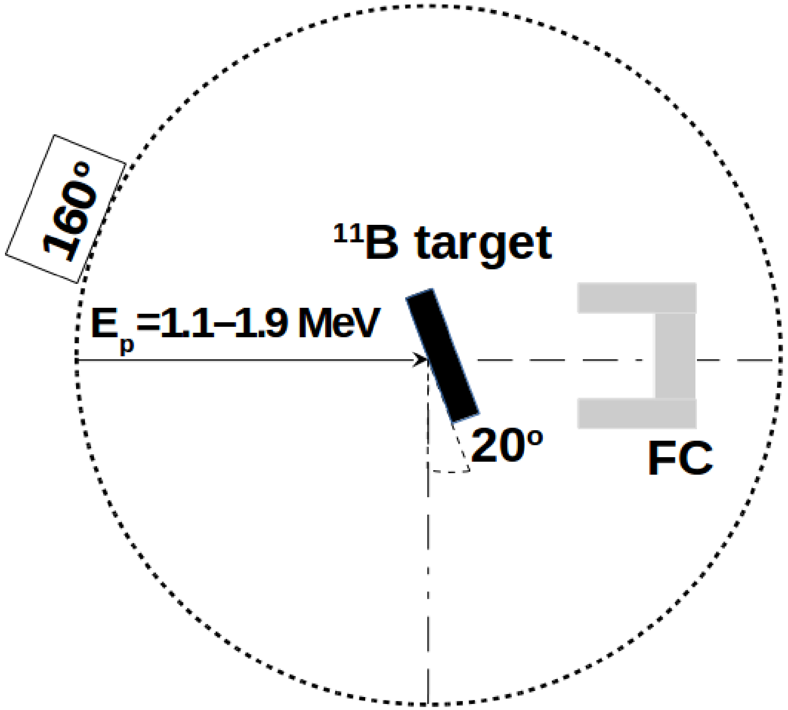
2/ For light targets (e.g. ^{11}B target): the experimental cross section data were taken from EXFOR compilation

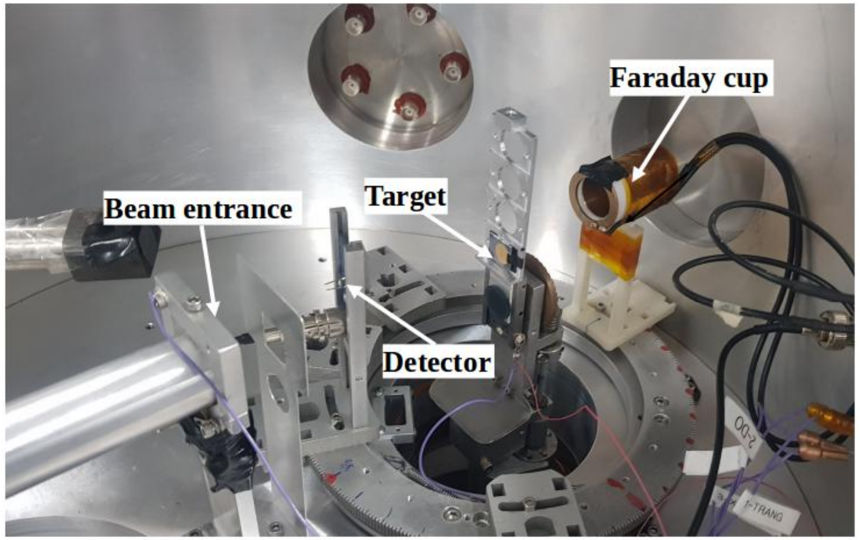


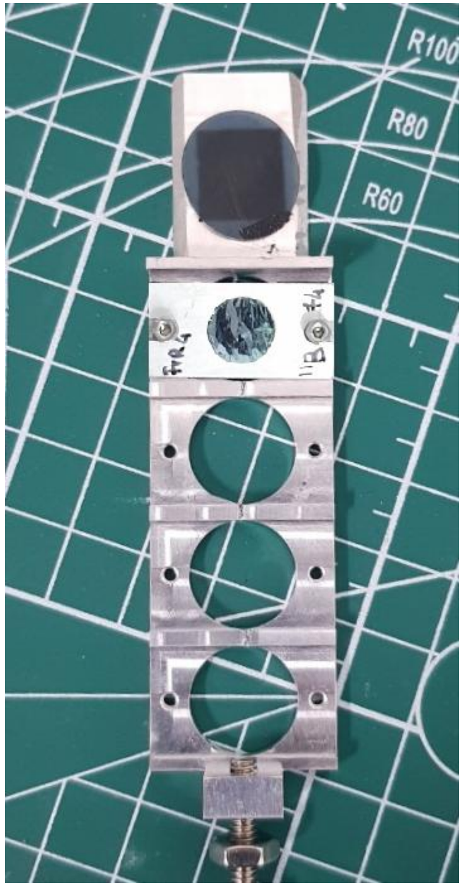
The experiment setup proposal

Table 1: The parameters setup

Channel reaction	$^{11}B(p, p_0)^{11}B$
Object measured	The target thickness
Target material	Enriched boron target (99% ^{11}B)
Target thickness (from supplier)	74 µg/cm^2 boron layer + 4 µg/cm^2 formvar substrate
Proton energy	1.1 – 1.9 MeV
Beam spot	3.3 mm diameter
Beam intensity	≈ 40 nA
Out-going angles	160^o
Distance detector – target (R)	6.4 cm
Collimator of detector (r)	0.4 cm radius

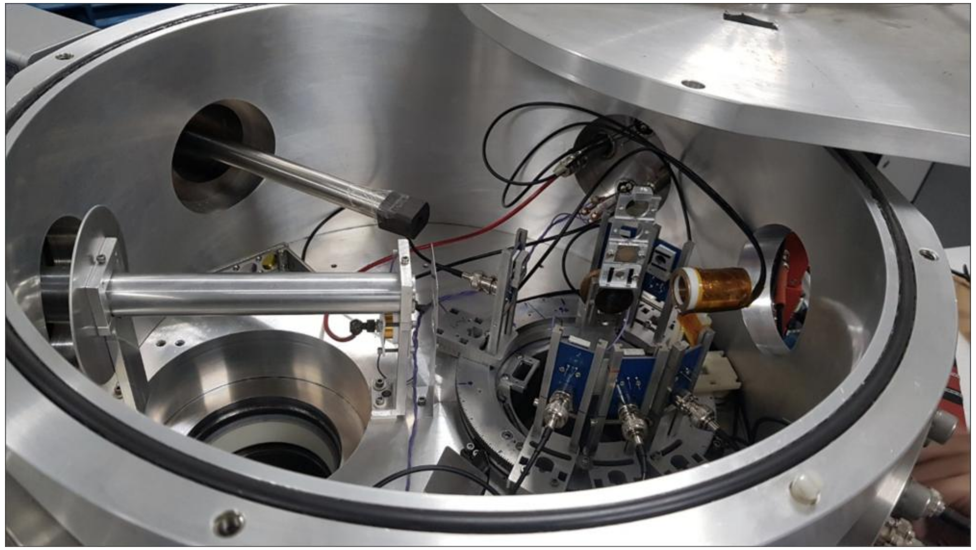






The proton beam was accelerated by Pelletron 5 SDH-2 accelerator

- **Ion sources:**
  - NEC RF Charge Exchange Ion Source (Alphatross)
  - Negative Ions by Cesium Sputtering (SNICS).
- **Available beams:** ^{1}H(p)(RF, SNICS), ^{2}H(d)(RF), ^{4}He(α)(RF), ^{6,7}Li(SNICS), ^{10}B(SNICS) …
- **Proton beam:**
  - E_p = 0.8 - 3.4 MeV
  - Intensity: 1-1000 nA
  - RF Alphatross, SNICS



Si PIN photodiode S3590-09 for the charged particles detection

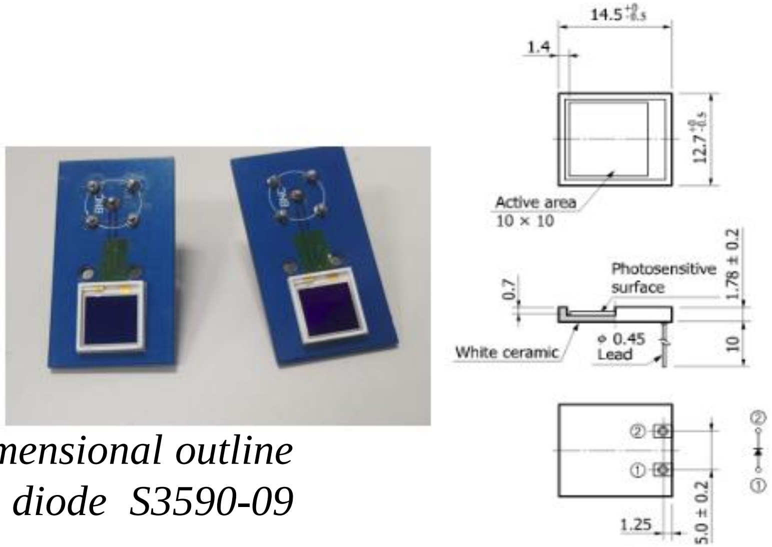
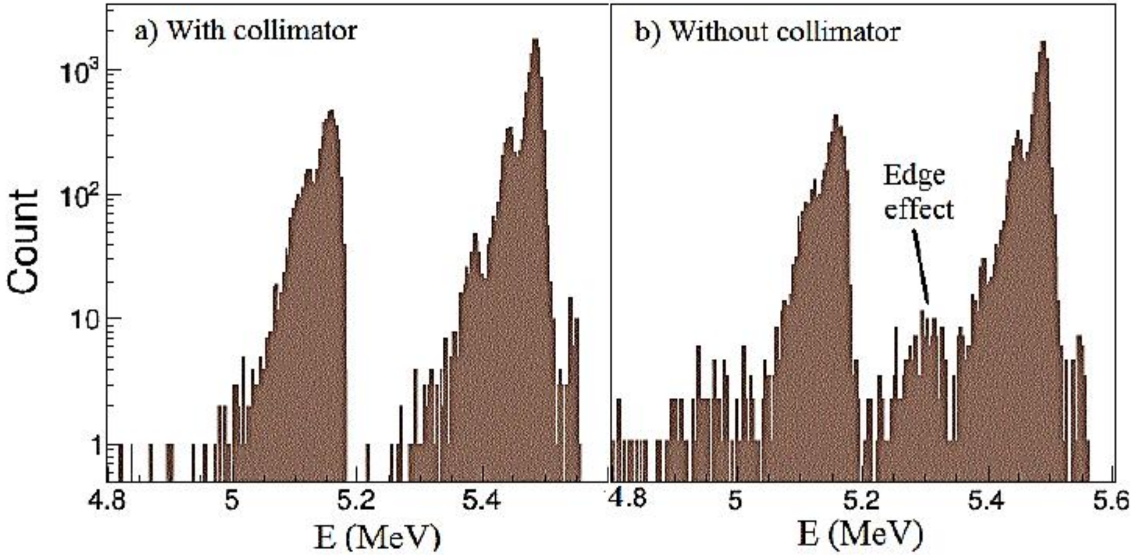
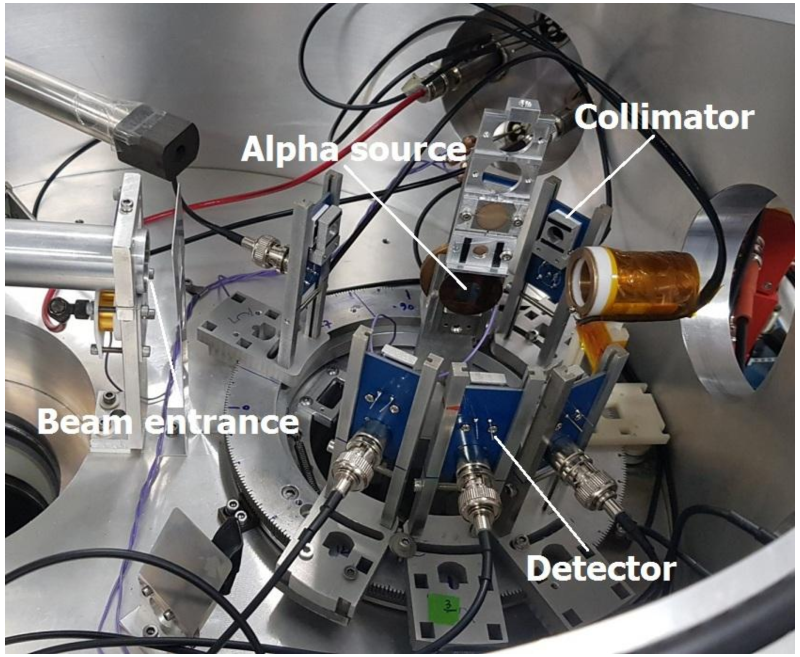
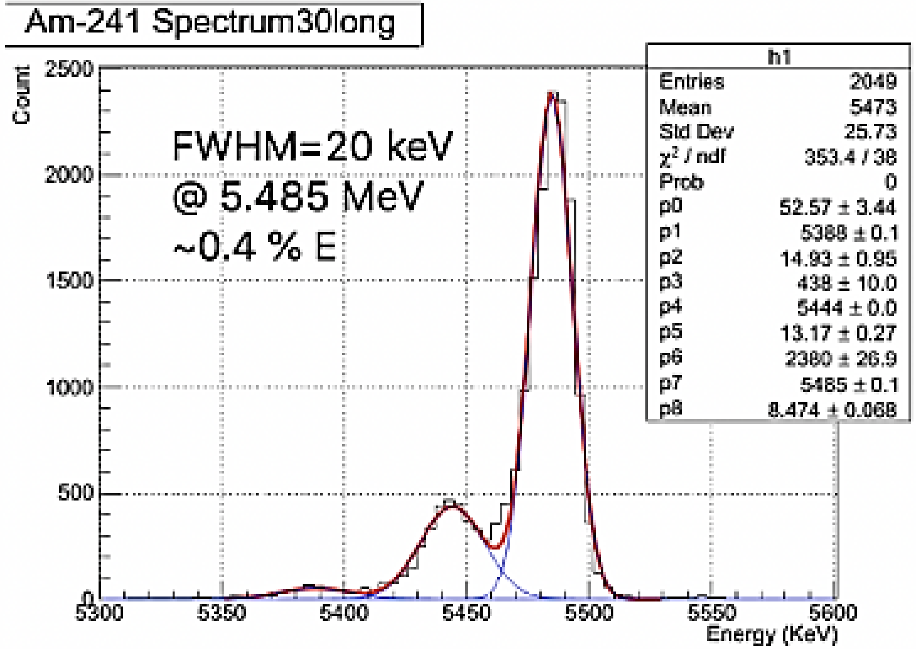


Photo and dimensional outline of a Si PIN diode S3590-09 (*)

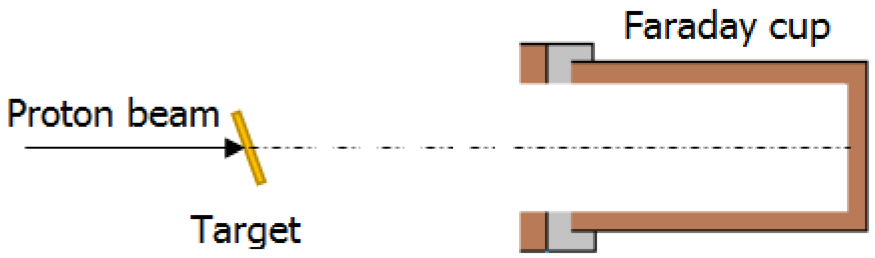


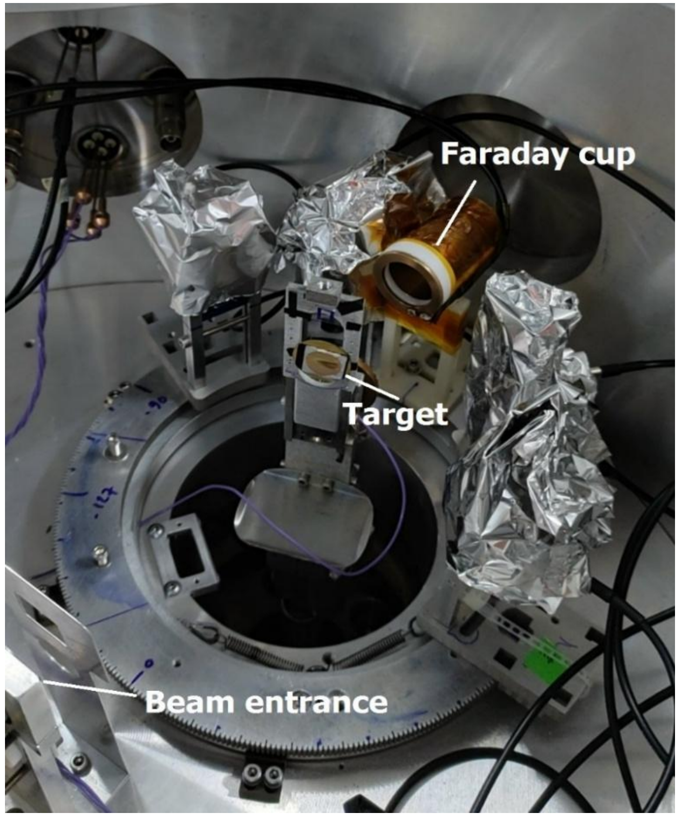


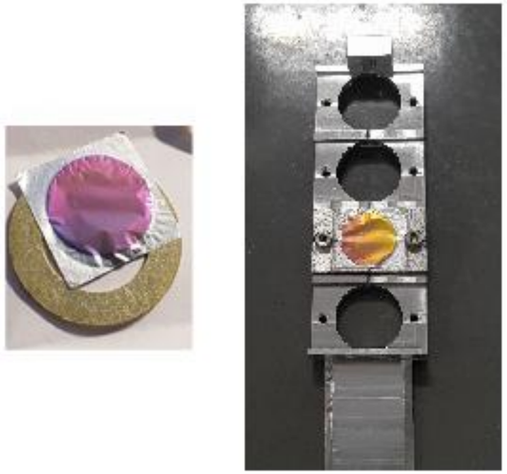


(*) https://www.hamamatsu.com/jp/en/product/optical-sensors/photodiodes/si-photodiodes/S3590-09.html

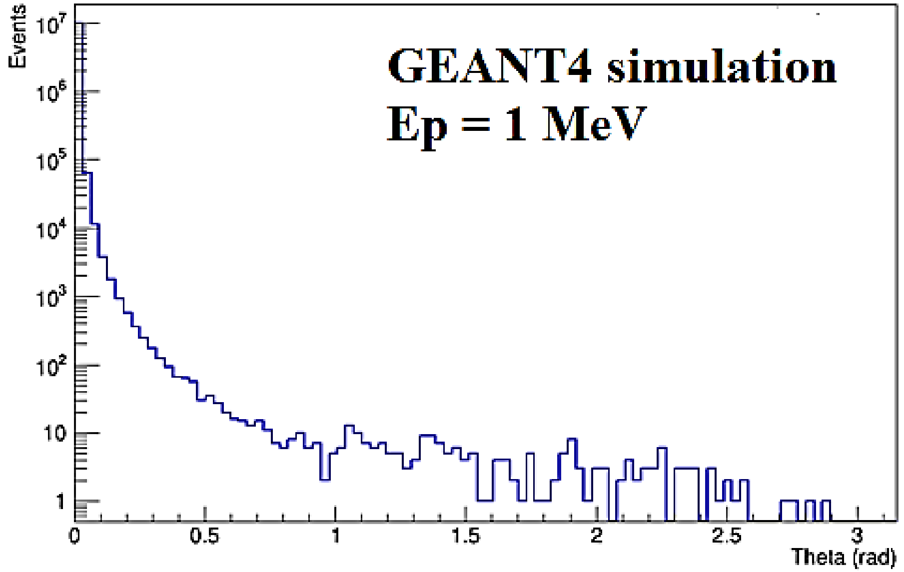
Faraday cup for beam monitoring



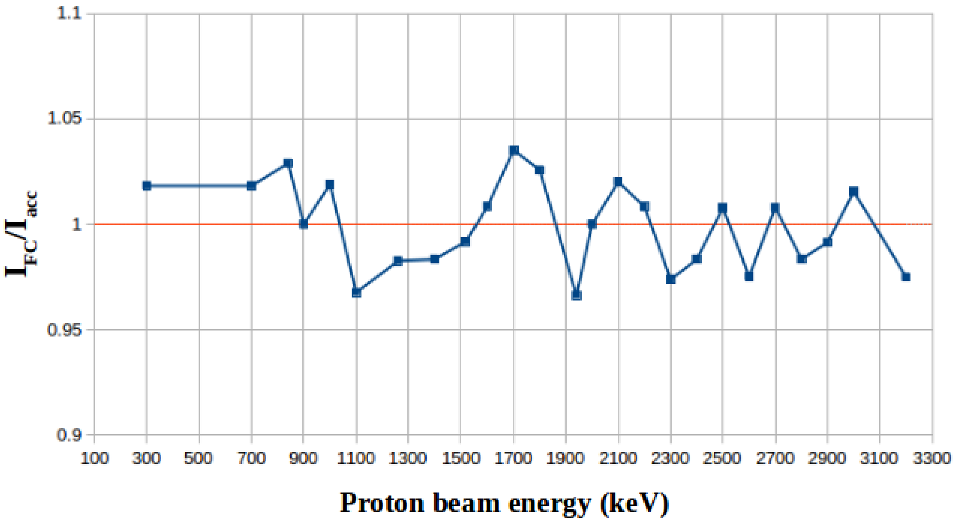




Natural boron target from Beijing Normal University



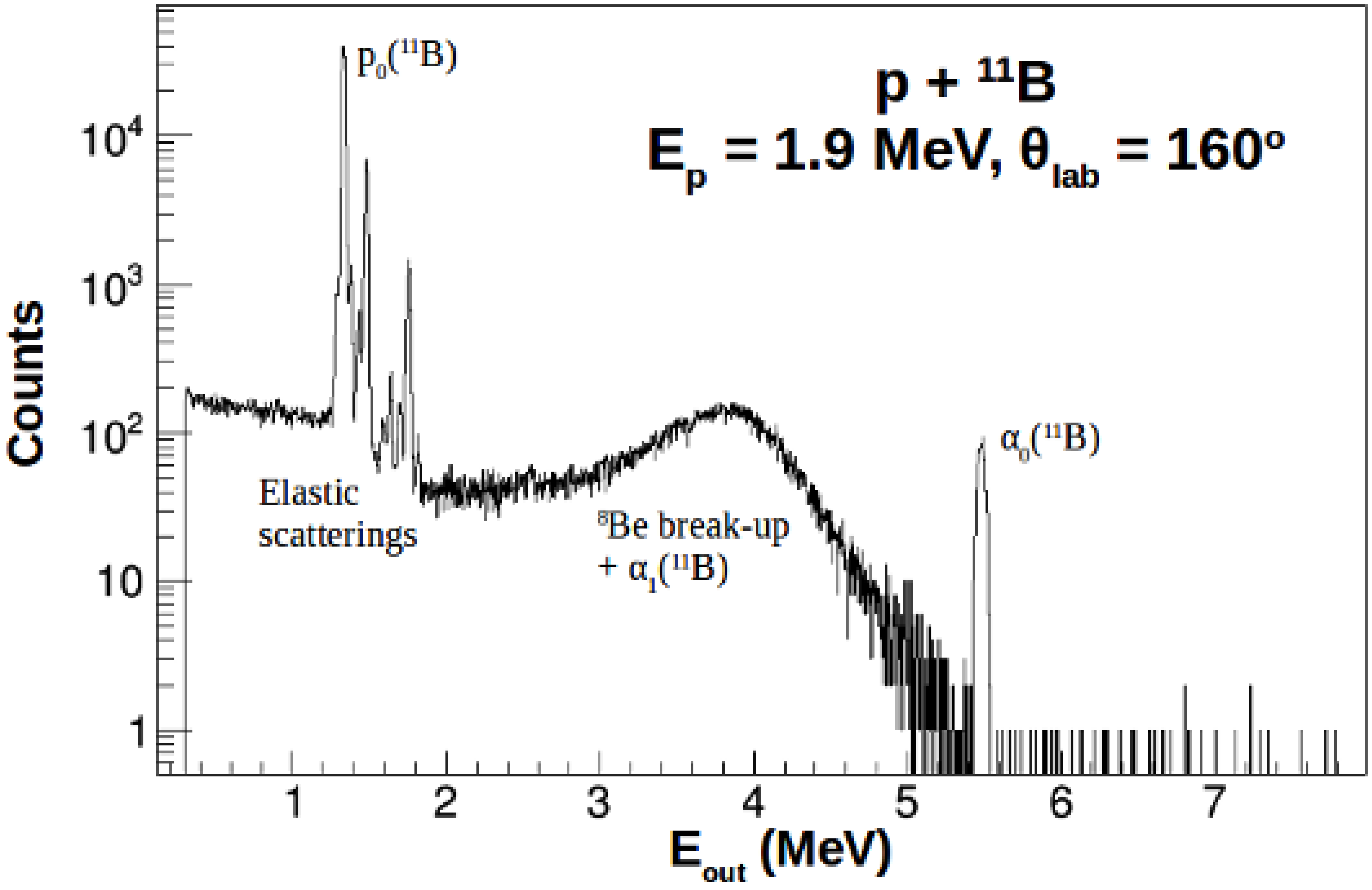
*Distribution of beam after target in GEANT4**

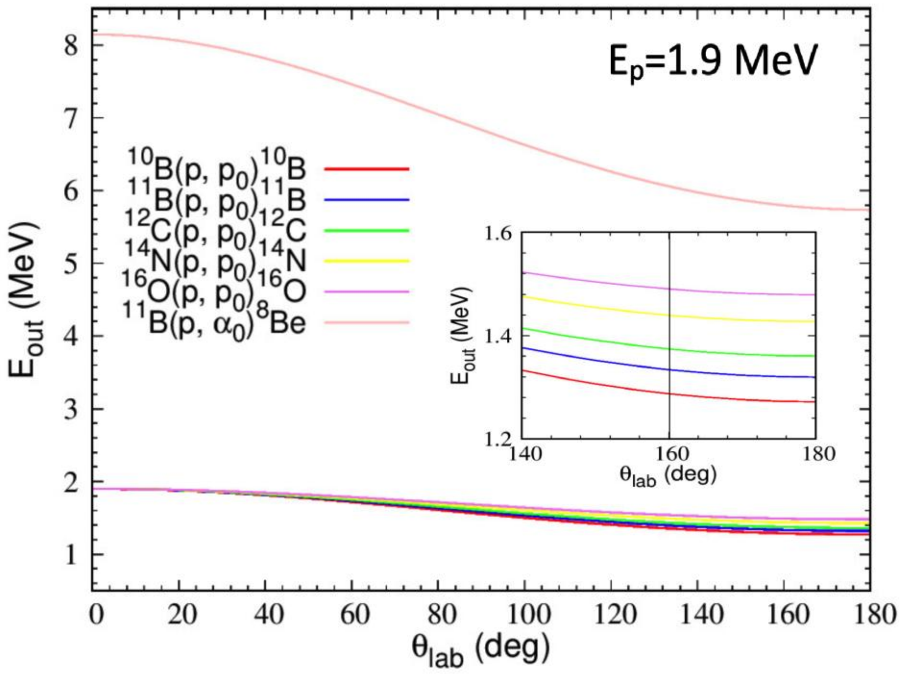


*Ratio of beam intensity measured in FC cup and FC of accelerator**

*(*) **M. V. Dien**, et al ,"A study of Faraday Cup to measure beam intensity on accelerators", [Presentation] The 7th Young Staff Nuclear Science and Technology, 2022*

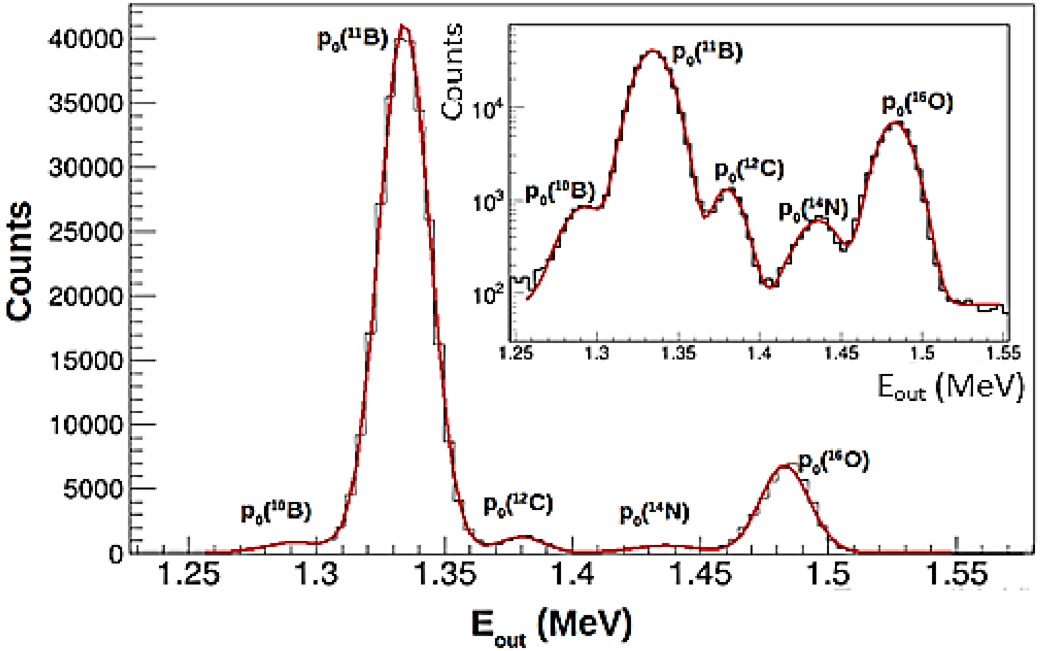
Experimental results

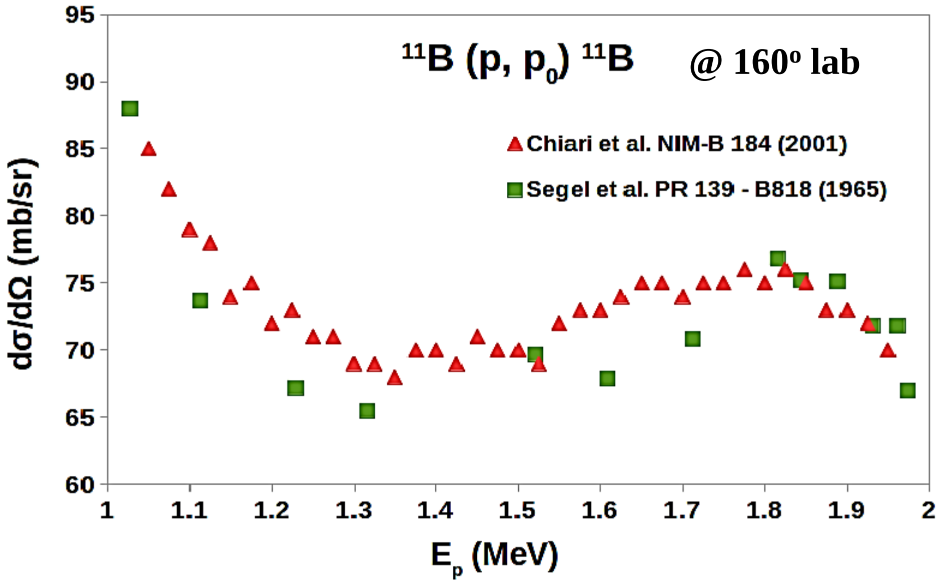




Kinematic plots for some reactions induced by E_p= 1.9 MeV

Determination of target thickness





The target thickness *d* (in g/*cm*²):

$$\boxed{d = \frac{N_t . M_A}{n_A . N_A} = \frac{Y \cdot M_A}{\frac{d\sigma}{d\Omega} \cdot N_p \cdot \Delta\Omega \cdot n_A . N_A}}$$

Where

Y: the experimental yield,

N_t : the number of target nucleus/ the target thickness

$\frac{d\sigma}{d\Omega}$: the differential cross section of $^{11}B(p,\ p_0)$ reaction

N_p : the number of impinging protons,

n_A: the enrichment of target (99%),

ΔΩ: the solid angle subtended by the detector.

Experimental target thickness

Table 2: the ^{11}B target thickness (d) determined from $p+^{11}B$ elastic scatterings at different proton energies

E_p (MeV)	**d (μg/cm²)**			
	Using cross sections from [a]	**Using cross sections from [b]**	**Average**	**From the supplier**
1.1	62.27 (400)	65.41 (352)	**61.50 (355)**	74
1.3	61.13 (413)	64.27 (347)		
1.5	61.46 (421)	61.90 (334)		
1.7	58.69 (317)	61.82 (333)		
1.9	58.31 (314)	59.74 (322)		

[a] **M. Chiari** *et al.*, *NIM B*, **184**(3), 2001, Pages 309-318.
[b] **R. E. Segel** *et al*, *Physical Review* **139**, B818 –1965.

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- **17% lower than the value provided by the supplier**
- **Strongly depend on the cross section, and the FC readout**

[a] **M. Chiari** *et al.*, *NIM B*, **184**(3), 2001, Pages 309-318.
[b] **R. E. Segel** *et al*, *Physical Review* **139**, B818 –1965.

Conclusions and future perspectives

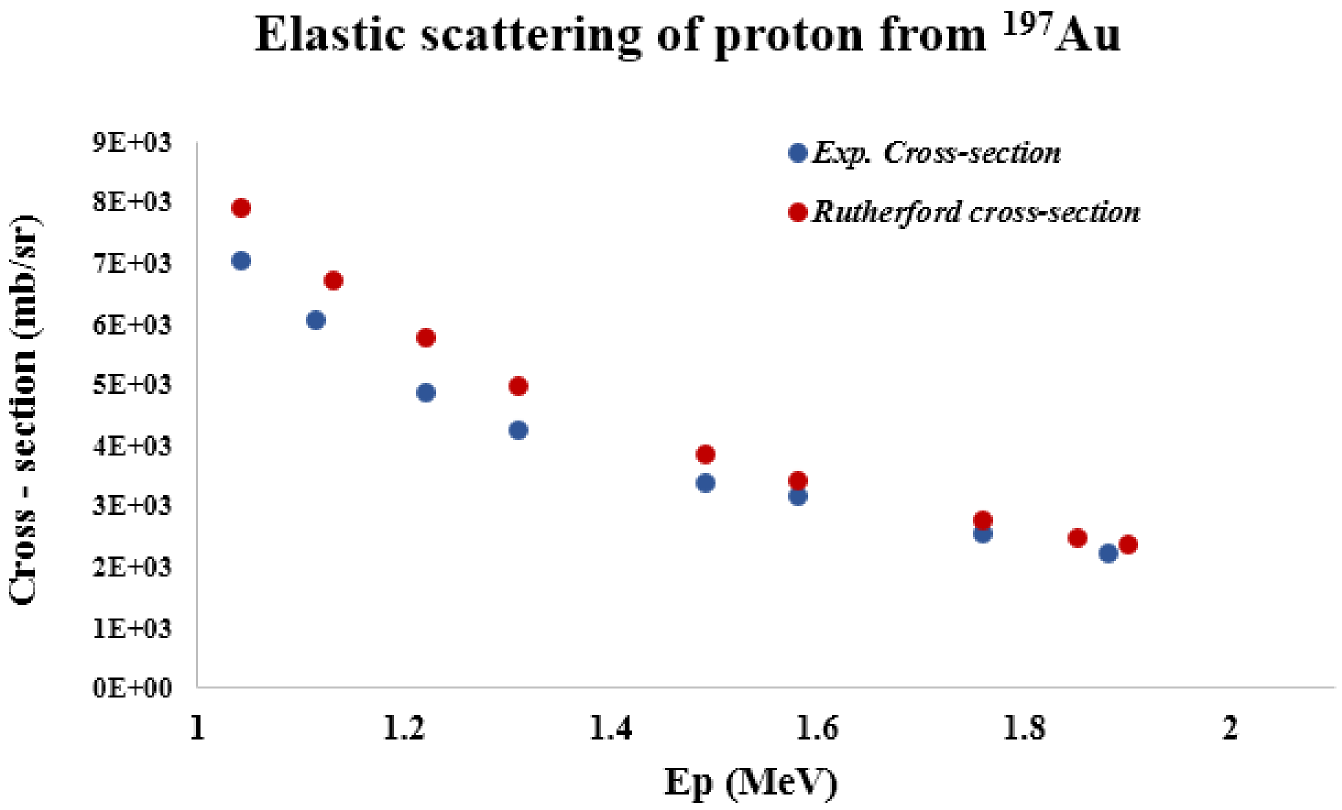
- The ^{11}B target thickness was measured by using the elastic scattering of proton beam.
- The thickness of 61.50 (355) μg/cm^2 was obtained, about 17 % lower than that provided by the supplier.
- The accuracy of the thickness is highly dependent on the available elastic scattering cross-section and the FC readout.
- To improve the latter, a well-known experiment (e.g. the p+^{197}Au elastic scattering) is being carried out to calibrate for the FC readout to overcome the charge collection problem.

Thank you for your attention!

Back-up slides

- **Integrated beam charge of 14 μC** → $N_p = 8.73 \times 10^{13}$ particles

- **Solid angle** $\Delta\Omega = \frac{\pi \cdot r^2}{R^2} = \frac{\pi \cdot 0.4^2}{6.4^2} = 0.01227$ sr



A factor of 1.08 – 1.18 for the discrepancy