Measurement of Fragment Production Cross-section on Nucleon-induced Reaction

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- Summary

1. Back ground 1

- **The radiation effects** (e.g. SEU : Single Event Upset) by cosmic rays in microelectronics, on board aircrafts as well as at sea level, have recently become serious problem and attracted much attention.

The most important particles on SEU phenomena are

Neutron

(spallation neutrons, created in the atmosphere by cosmic-ray)

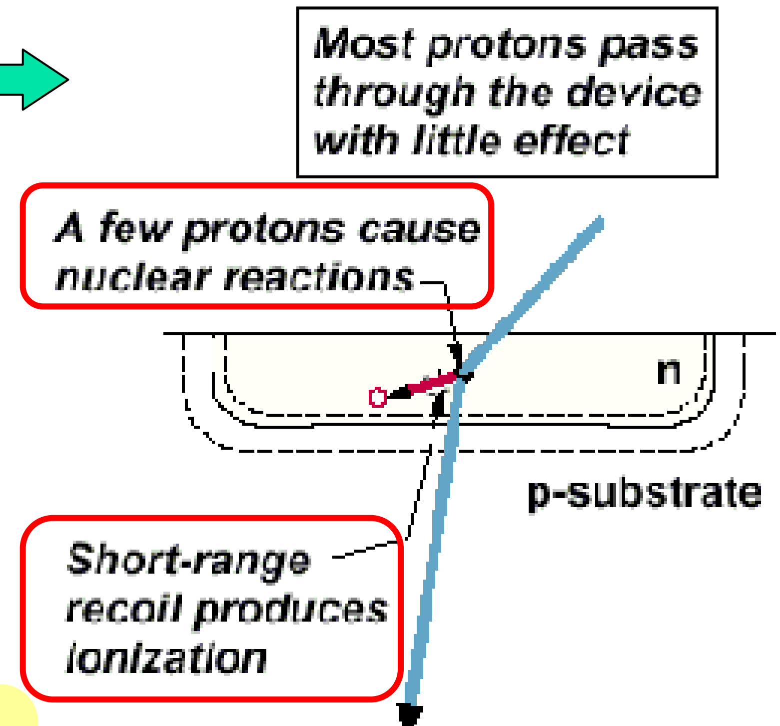
Proton

makes radiation effects

- **Nuclear reaction**

→Secondary Charged Particle

: Ionization and Energy deposit



(e.g.

Protons *(nuclear reaction needed to produce recoil)*

Secondary particles heavier than α (=fragments); large LET > Qcritical

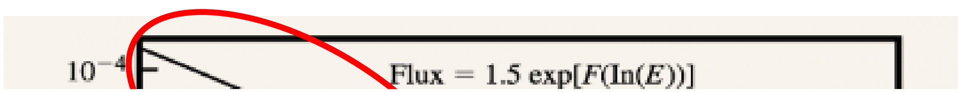
Main course of SEU

1-2. Back ground 2

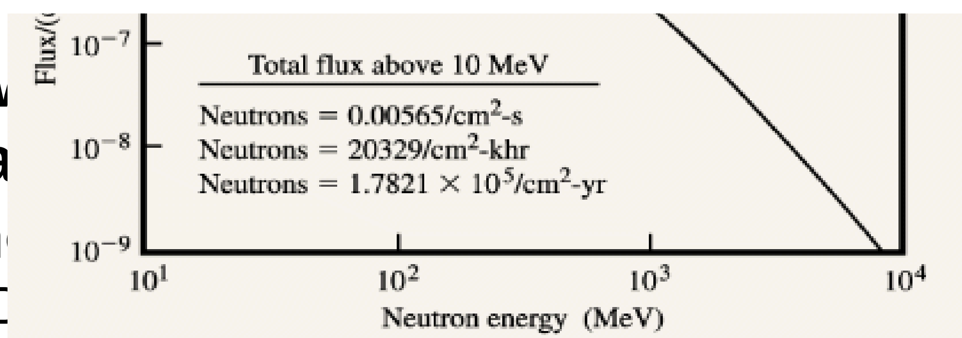
Data on fragment production yield including energy and angular distribution (Double differential cross-section; DDX) by neutron and proton are required in SEU estimation

Energy info.・・・・・・・Energy deposition on device
Angular info.・・・・・・・Energy spectrum has large angular dependence

Especially, Intermediate energy region (ten's of MeV – several 100 MeV)



- **Important ・・・・ dosimetry for human**
  - in space environment
  - in proton radiotherapy up to ~ 250 MeV



Hov

Data … y poor

am

- Neutron flux at sea level by IBM

2. Present status on fragment production data

For light charged particles, p, d, t, α,
several experimental data have been reported,

For fragments (A>4)

For neutron

Data above 20 MeV ･････few data by activation method
No information on energy and angular distribution

For proton

Above 1 GeV･･････several data by nuclear physics
Below 1GeV･･･････activation and mass separator
No information on energy and angular distribution

Energy and angular distribution data ････ only two following

target	projectile	energy (MeV)	author	method
C	p	45,100	C.T.Roche et al. (1976)	E-TOF
Al	p	180	K.Kwiatkowski et al. (1983)	E-TOF

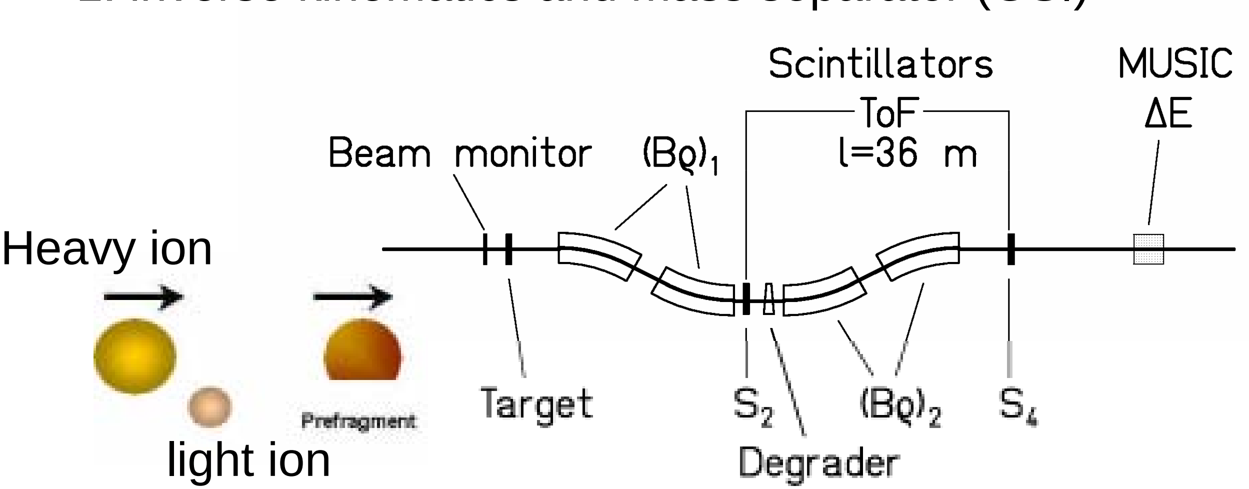
2-2.fragment experiments in progress

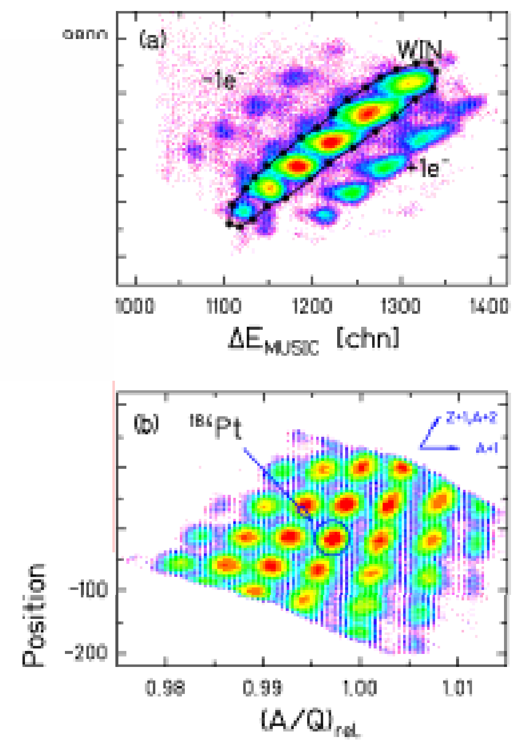
Nuclear physics experiment

Above 1 GeV/u

1. inverse kinematics and mass separator (GSI, MSU etc.)
2. Recoil measurement (KEK,MSU etc.)

1. inverse kinematics and mass separator (GSI)





- TSL (Uppsala) just started in 2004

Planning 100 – 470 MeV/u using Si → H

Clear identification Z,A but difficult to deduce information of energy and angle

2-3.fragment experiments in progress 2

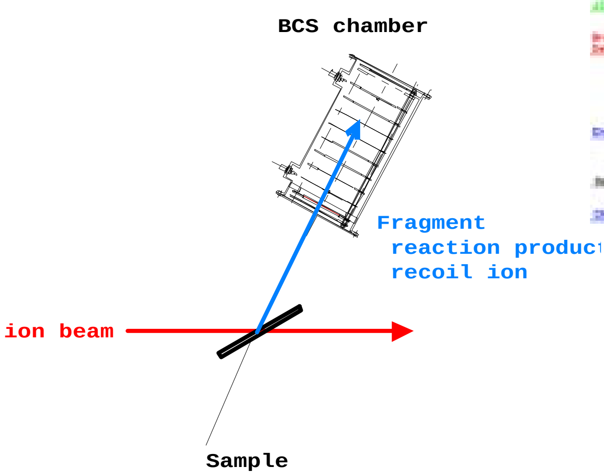
2. Recoil measurement

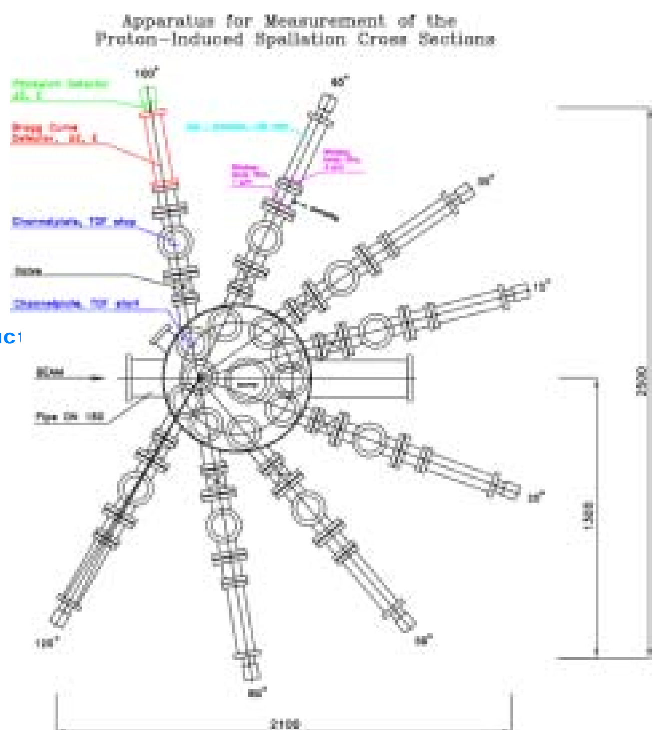
BCS (Bragg Curve Spectrometer) mainly used (KEK, MSU, FZJ)

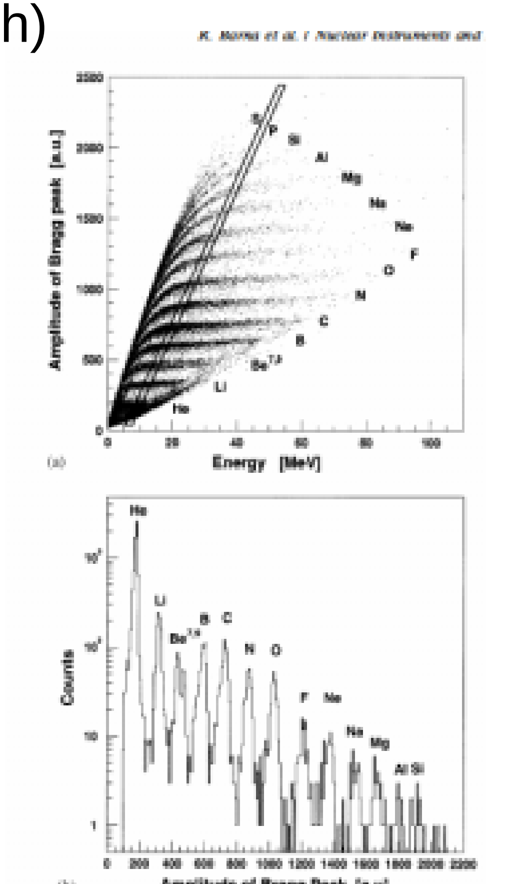
high energy region (>1 GeV/u)

PISA (proton-Induced SpAllation experiment) FZJ (Julich)

planning 200-2500 MeV proton







2-4. Calculation

Data library

LA150 (LANL) <150 MeV
Calculated with GNASH code
A>4 isotropic angular distribution

Nuclear Models (treat fragment production)

GNASH (LANL) <150 MeV limited
CEM (LANL): Cascade Exciton Model
JQMD (JAERI): Quantum Molecular Dynamics model

Theoretical calculation treating fragment production is not validated and uncertain due to very few experimental data

3. Motivation of present study

Data on energy and angular distribution on fragment for Si, C ect.
(Double differential cross-section)

In ten’s MeV region ・・・・・・Important, but no data
For neutron and proton except for Roche’s data

Difficulty in the measurement
(**low yields, large energy loss** etc.)
Especially for neutron, the problem of low yield is critical for conventional counter telescope (ΔE-E method).

In the Fragment measurement,
Identification of fragment
Large detection area required.

3-2. in this study

Difficulty in Fragment Measurement

- Large energy loss in sample → thin sample
- Low yield → large solid angle (high efficiency)
- Variety of particles → particle identification

n

1) a **Bragg curve spectrometer (BCS)** gas counter
having the capability of various information with a single counter
special care **for neutron (and proton)**

p

2) an **energy-time of fight (E-TOF) method**
having the capability of mass discrimination in almost all energy region
for proton.

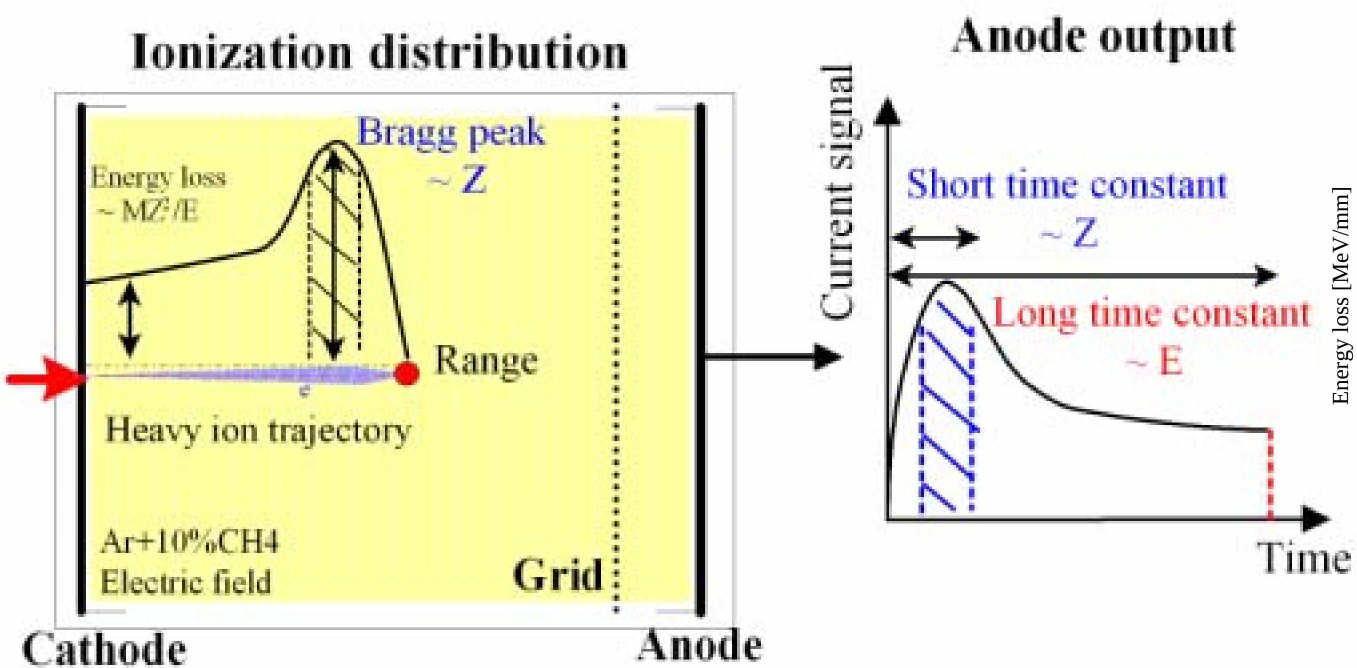
	THO	TSL	PISA	GSI etc.
enery range (MeV)	30 - 90	100 - 470A	200 - 2500	>1000A
projectile	n,p	Si	p	Pb, U ....
method	BCS for n,p E-TOF for p	inverse kinematics	BCS and E-TOF coupled	inverse kinematics
data	DDX	reaction XS	DDX	reaction XS

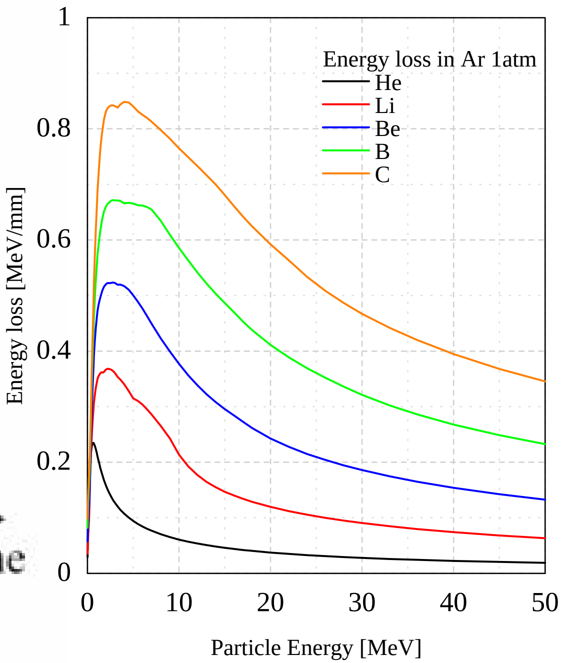
4. Bragg Curve Spectrometer [BCS]

Bragg curve spectrometer (BCS) based on gridded ionization chamber (GIC)

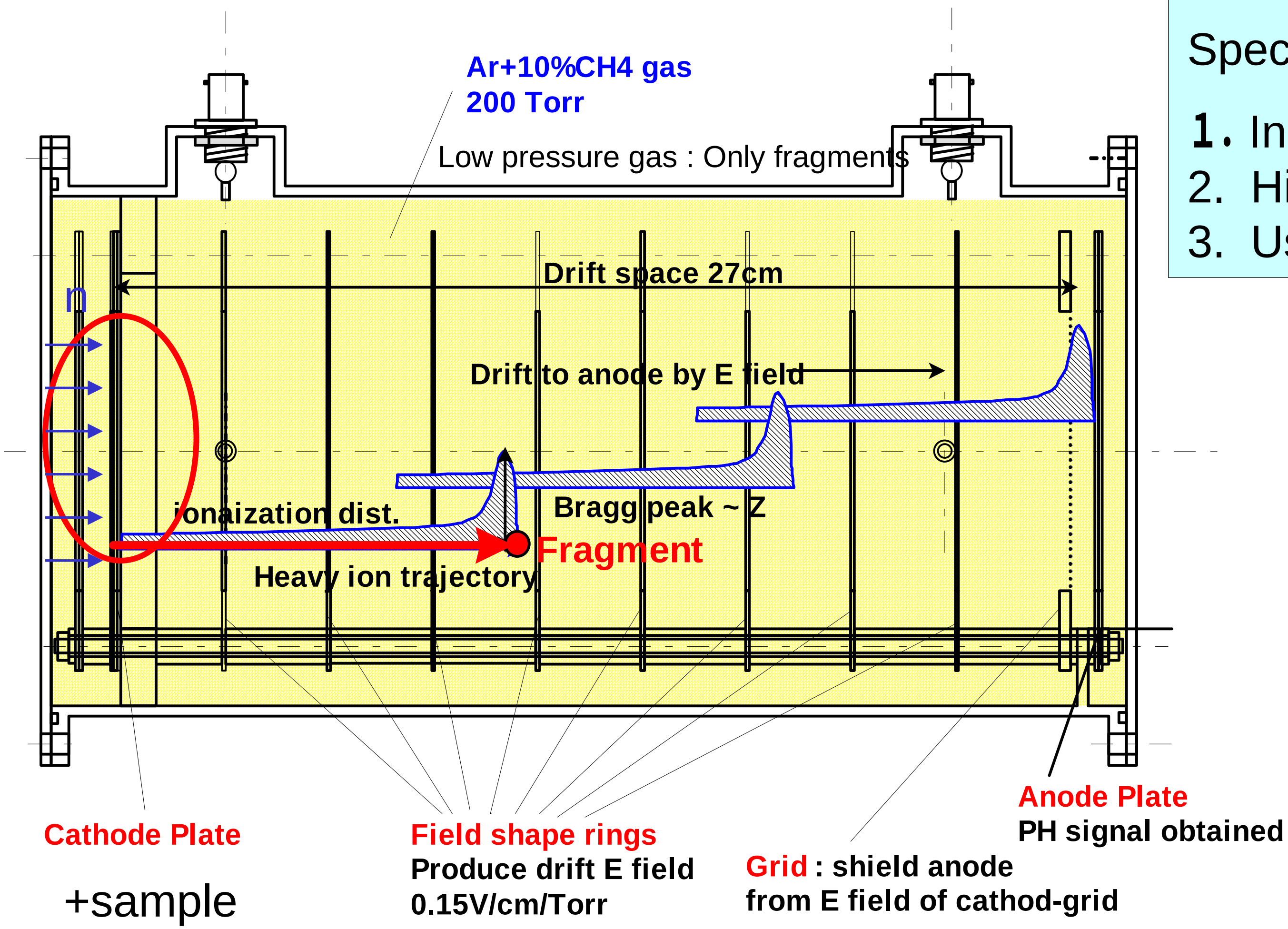
capability of various information (energy, charge, mass) with a single counter

- Bragg peak ← f(Z)
- Total energy vs Bragg peak → Particle Identification (usually)
- No ΔE counter, large solid angle and particle acceptance





4-2. The present BCS



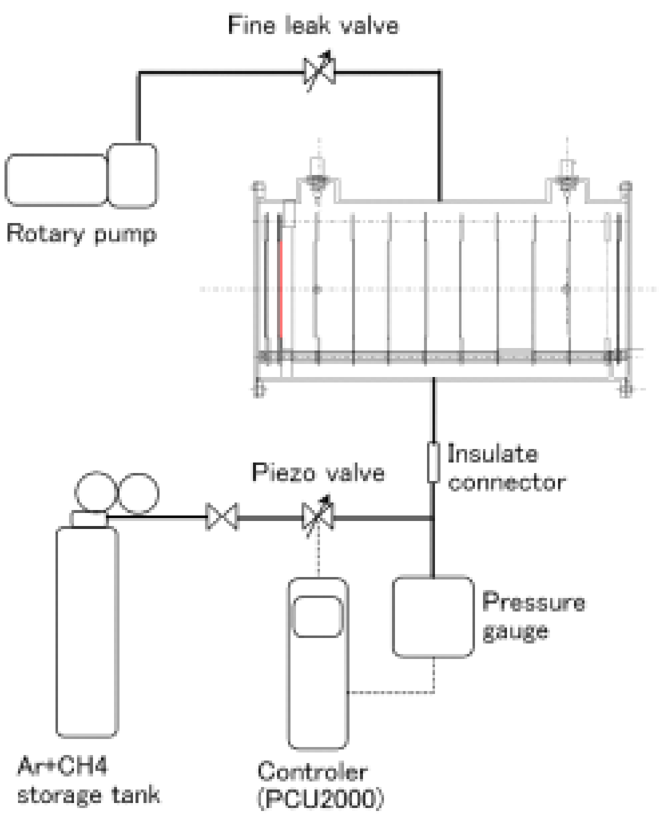
For neutron induced reaction

Special care

1. Inner sample,
2. High Z electrodes (Ta),
3. Use cathode signal

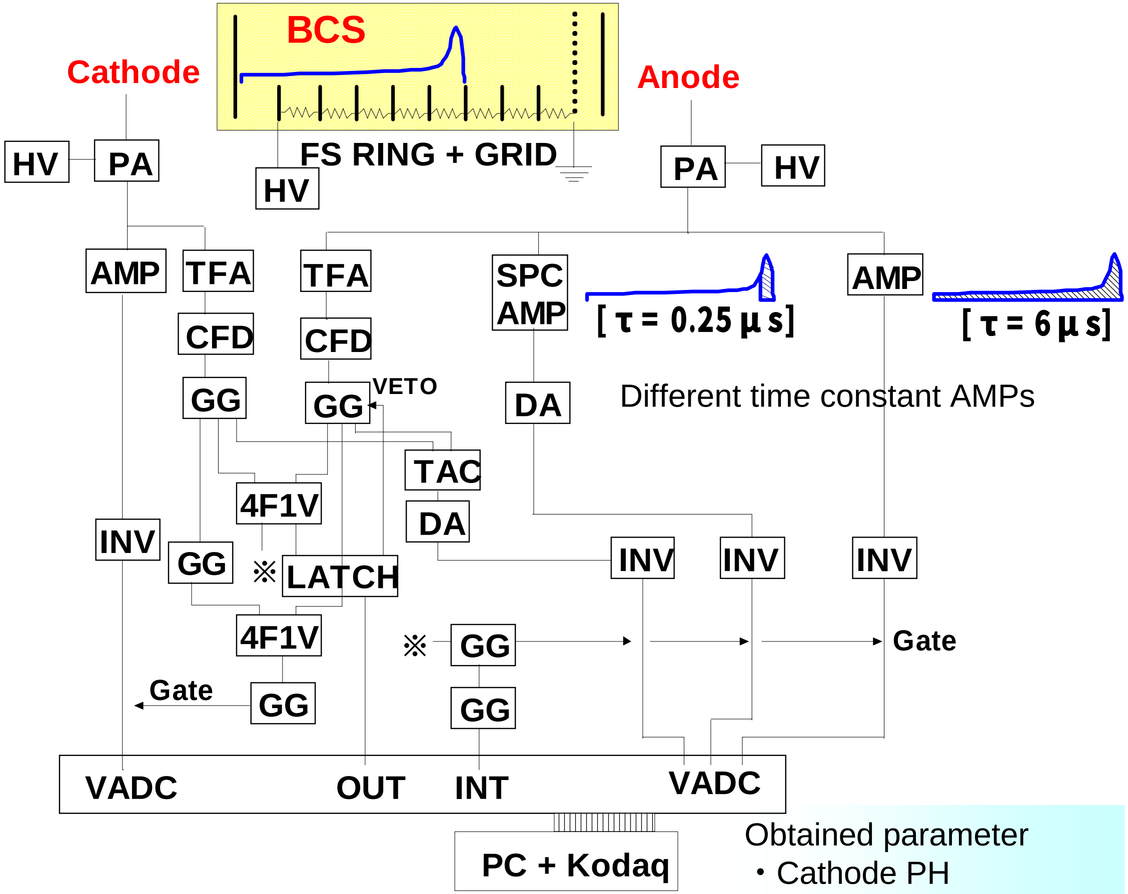
4-3. measurement system

4-3.1. Gas flow system



Keep the gas pressure to 200 torr

4-3.2. Electronic circuit

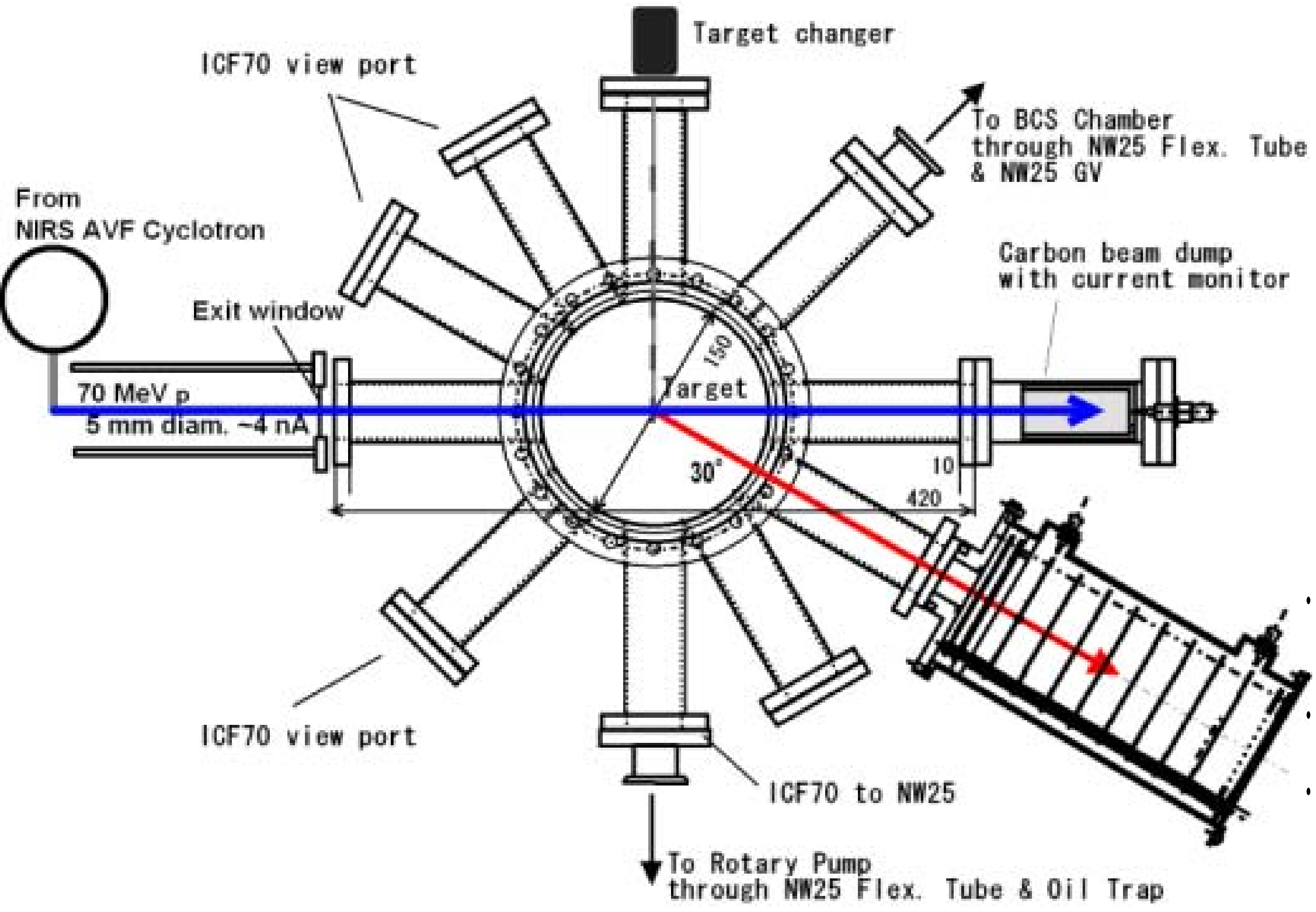


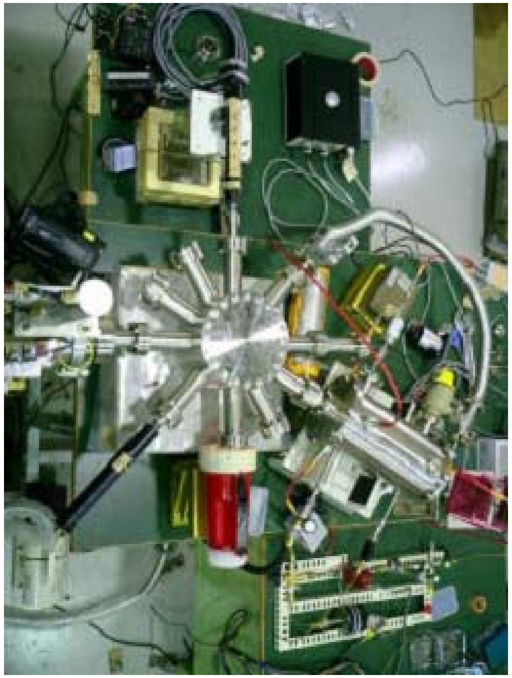
Obtained parameter

- Cathode PH
- Anode PH
- Bragg peak PH
- Cathode-Anode Timing

4-4. Experiment for Proton induced reaction

4-4.1. Experimental apparatus

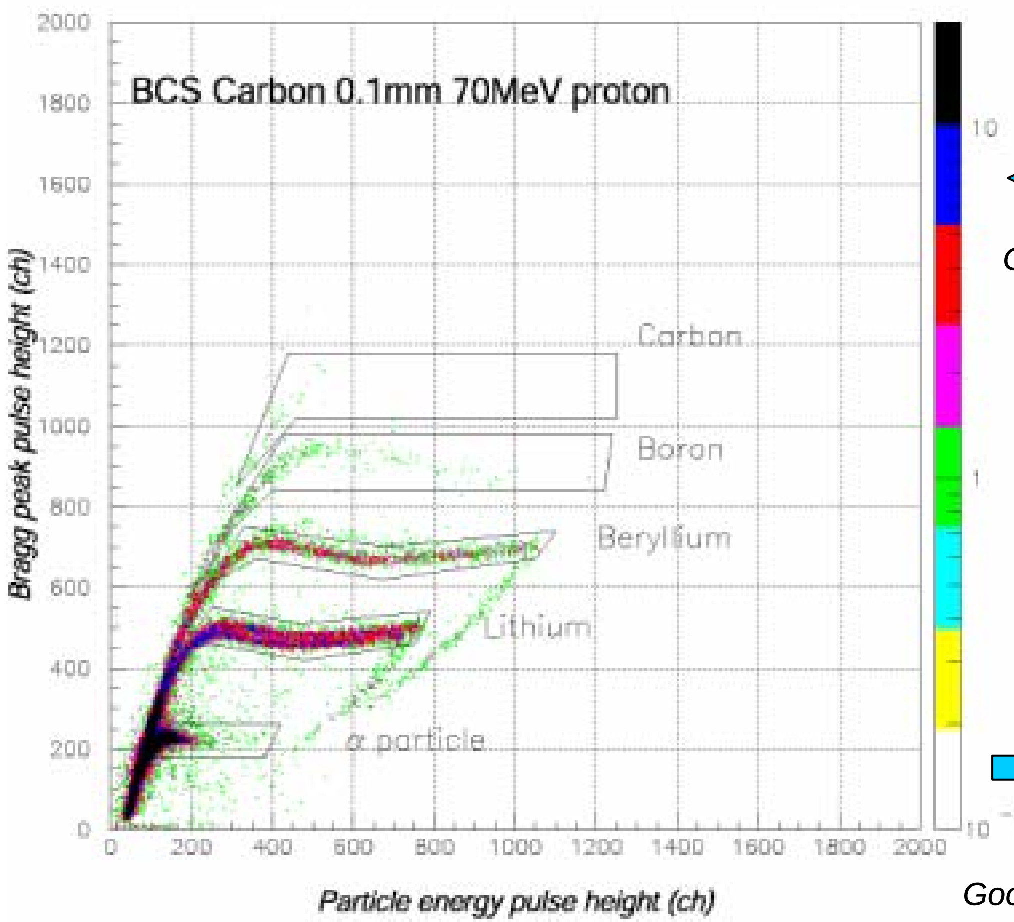




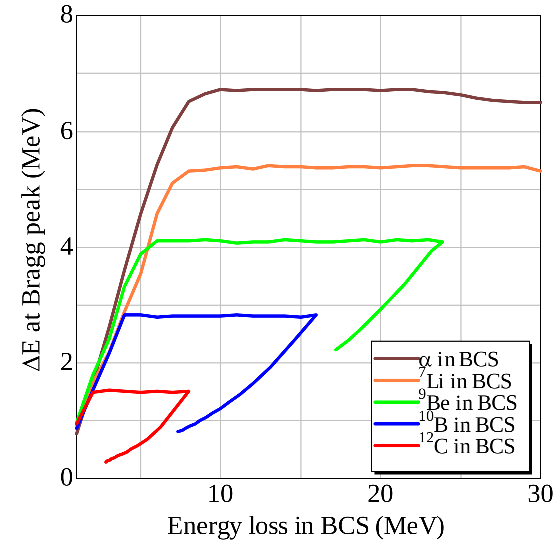
- Target： Polypropylene (4 μ m)
- Angle： 30 °
- Incident particle： proton
  70 MeV, ~4 nA
- Irradiation time：~2 hour

4-5. Results for proton induced reactions

Bragg peak vs. Anode



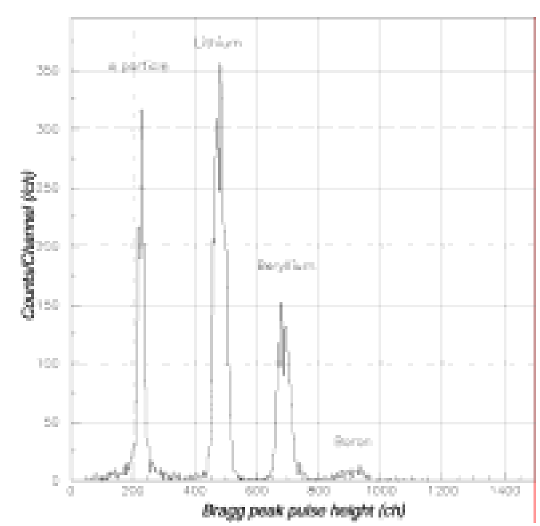
Simulation with TRIM code



Good agreement

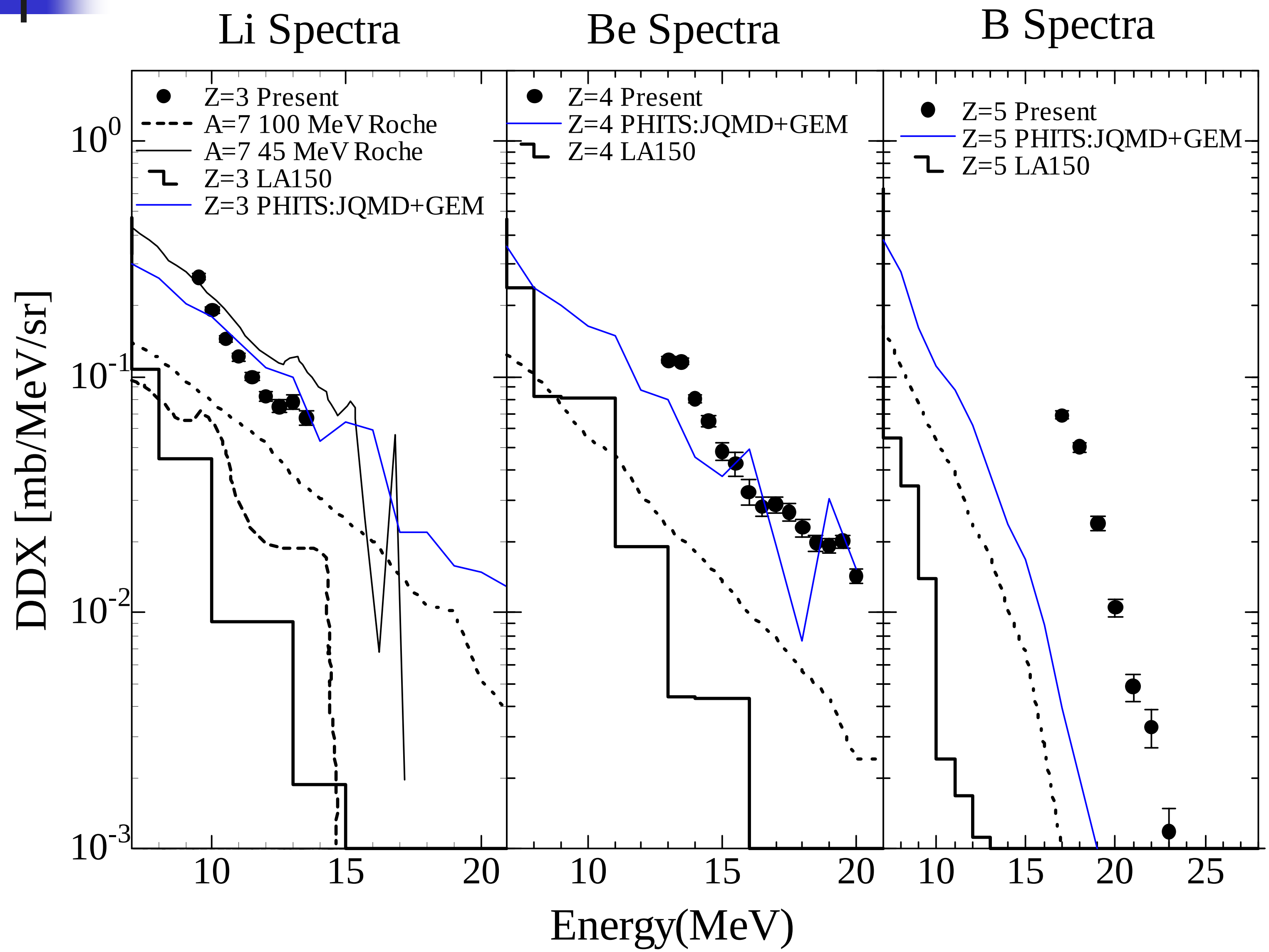
Good identification

(He~B)



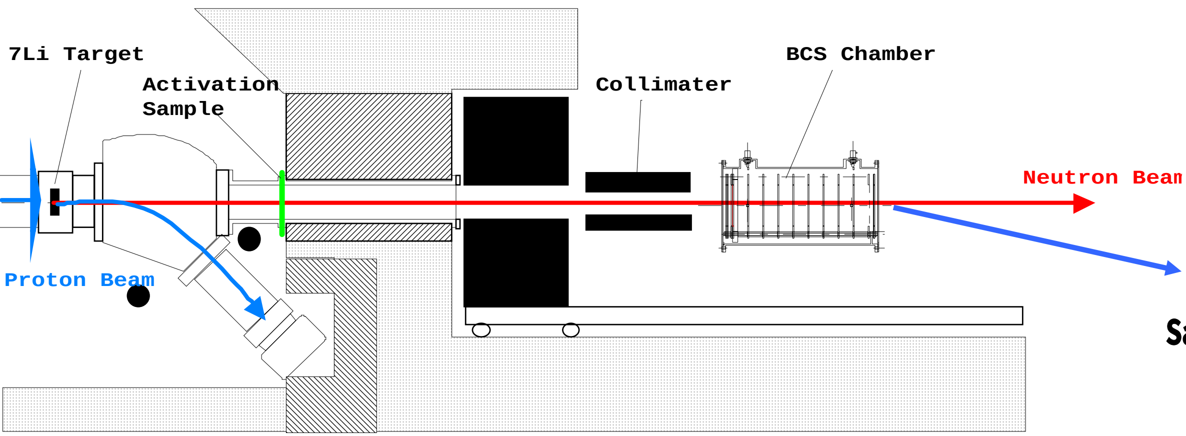
Target： Polypropylene (4 μm)
At 30 deg.

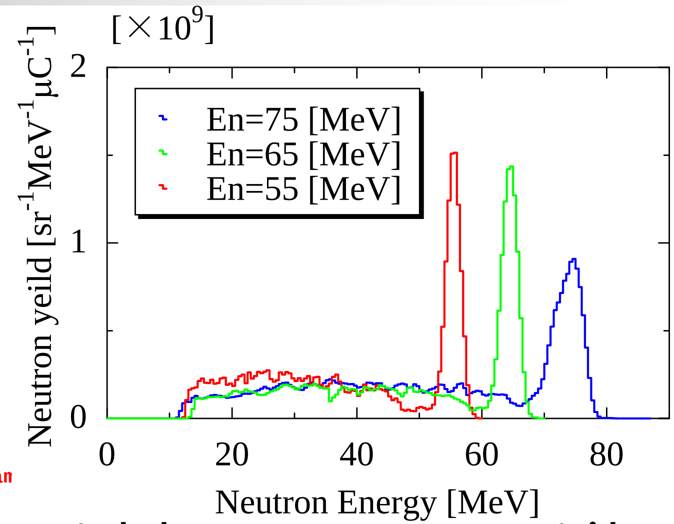
4-5.2. Results for p-C reaction

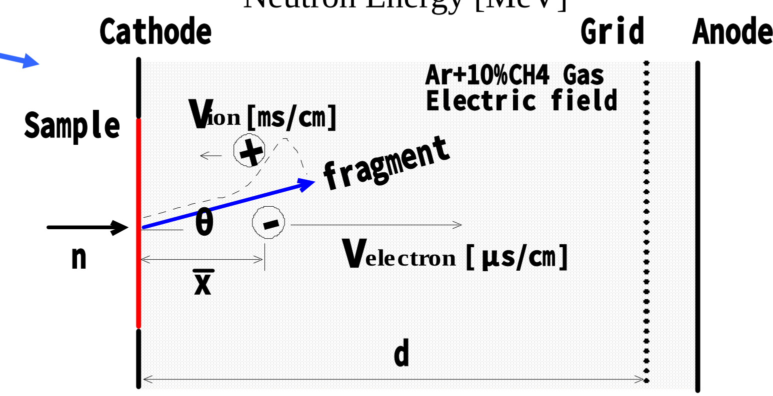


4-6. Experiment for Neutron induced reaction

- JAERI TIARA Li(p,n) En=65, 75 MeV
- Incident beam :collimated neutron
- Proton current 1μA







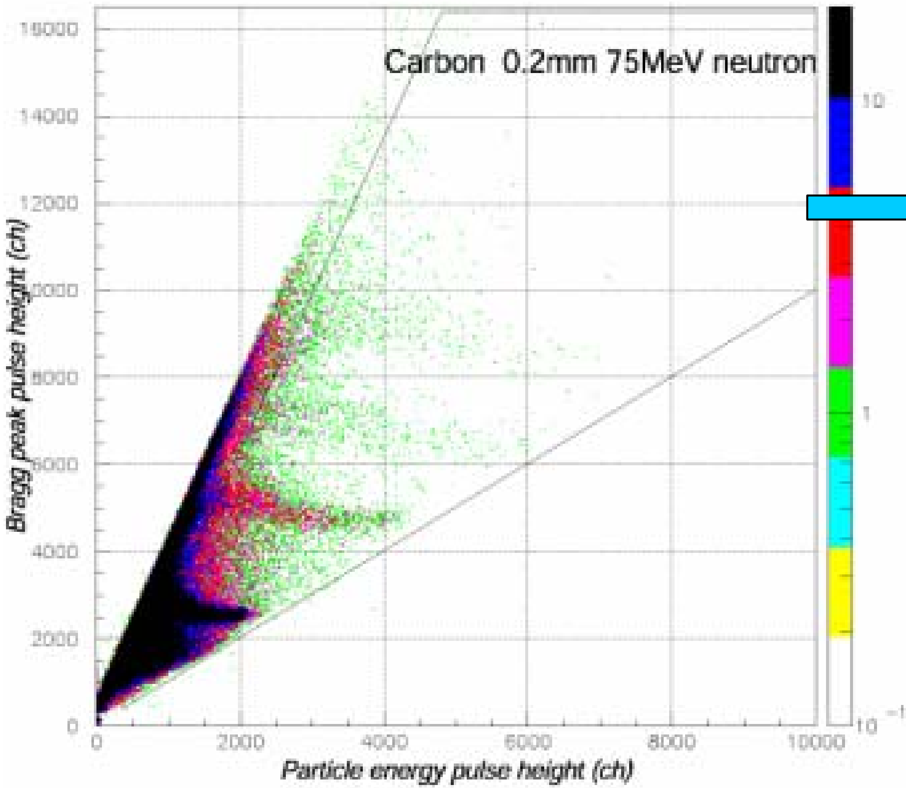
sample C(200μm)、Si(500 μm), Polypropylene (10μm)、Au(10μm)

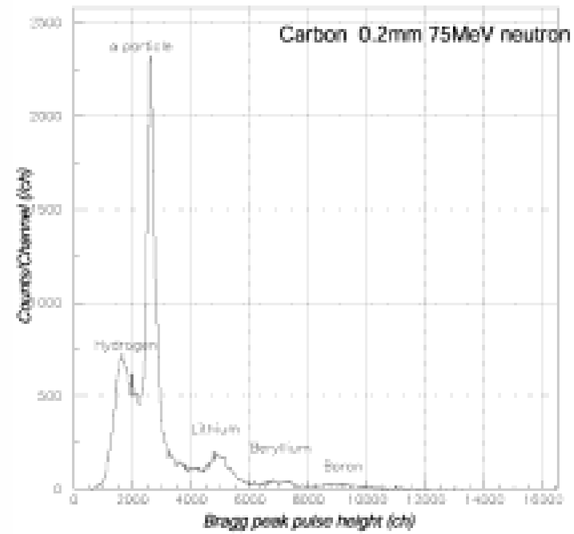
→ to know the yields and evaluate foreground and background events

- Pa=E+σPc
- Pc=E(1-x/d cos θ)
- Large area
- Large solid angle

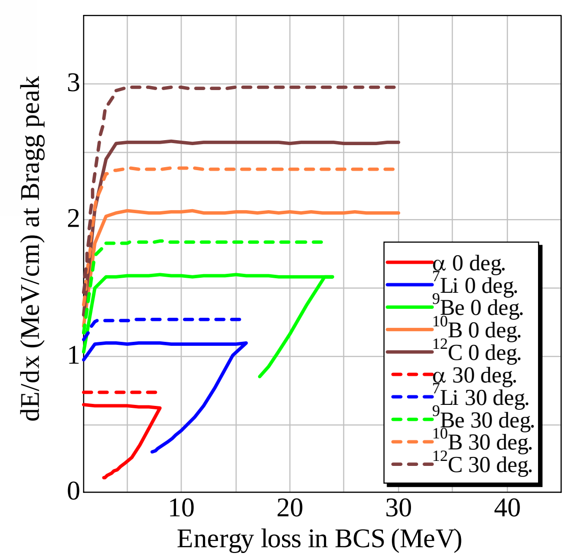
4-7. Results for neutron induced reaction

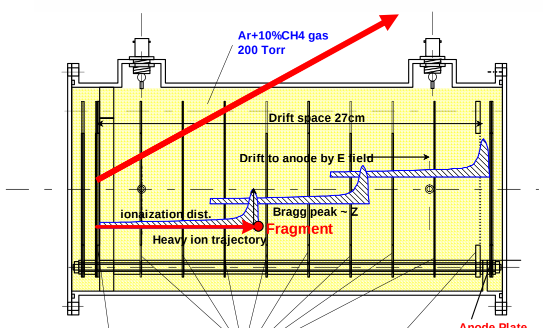
First results on neutron induced reaction !



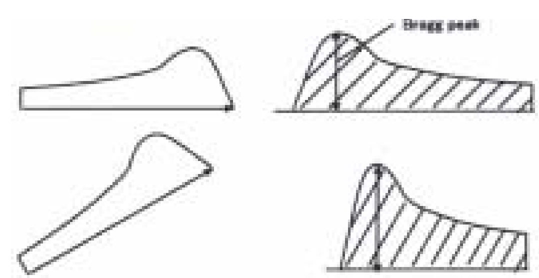


TRIM calc.

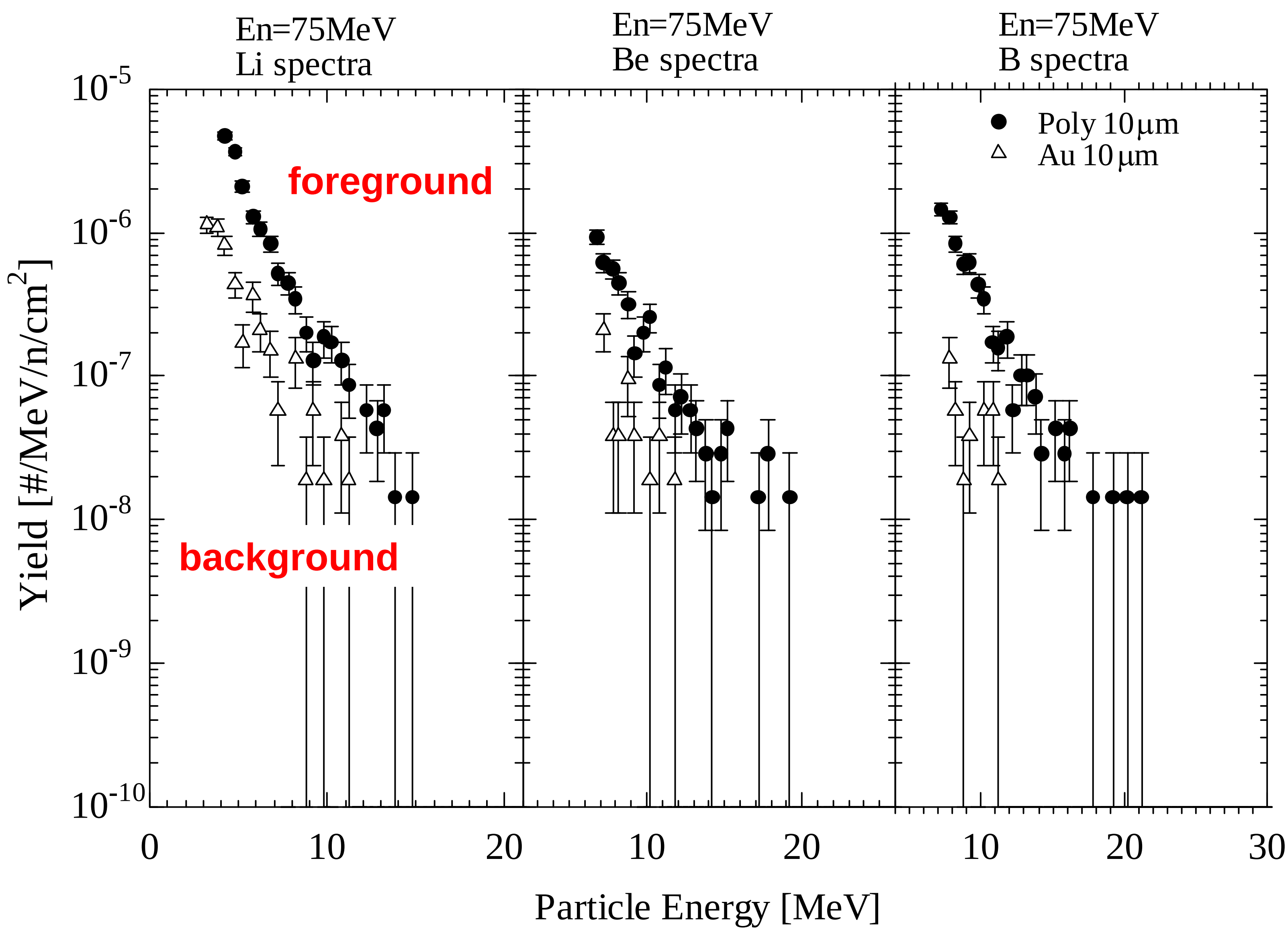




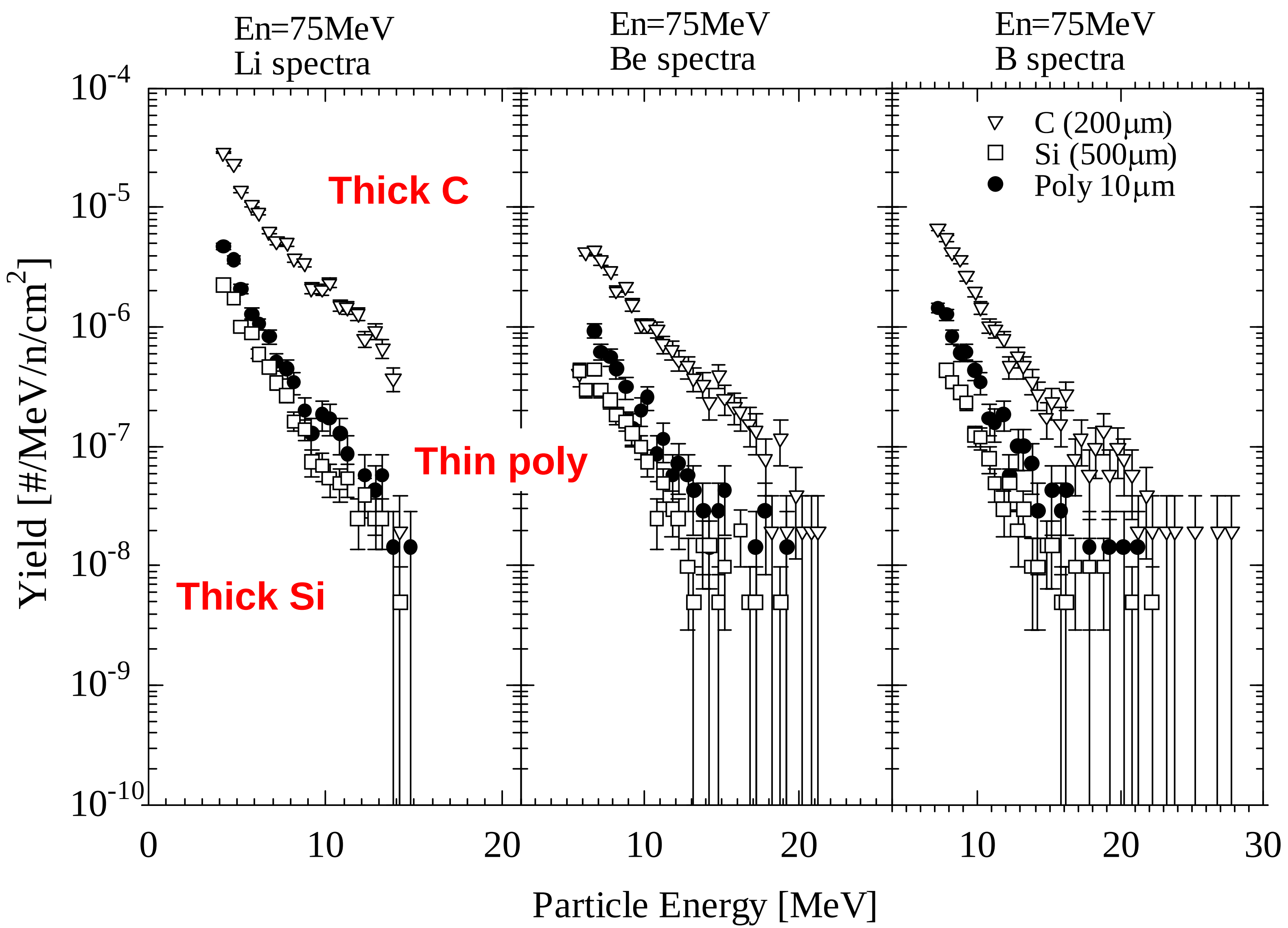
response for emission angle



4-7.2. Energy spectra (Li, Be, B) by 75 MeV neutron



4-7.3. Energy spectra (Li, Be, B) by 75 MeV neutron

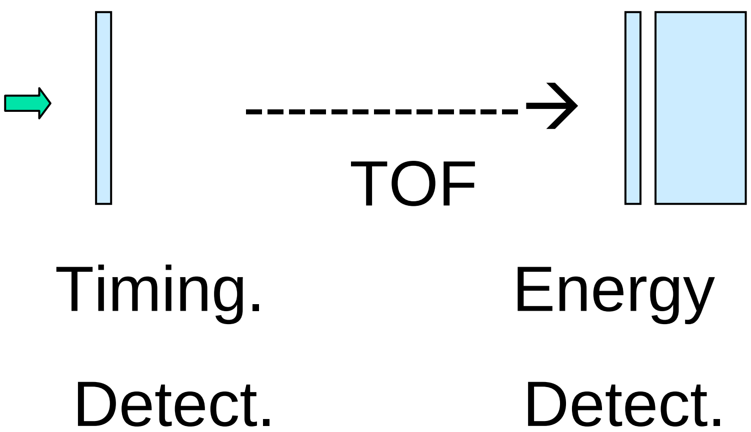


5. Energy-TOF method (E-TOF)

Low threshold

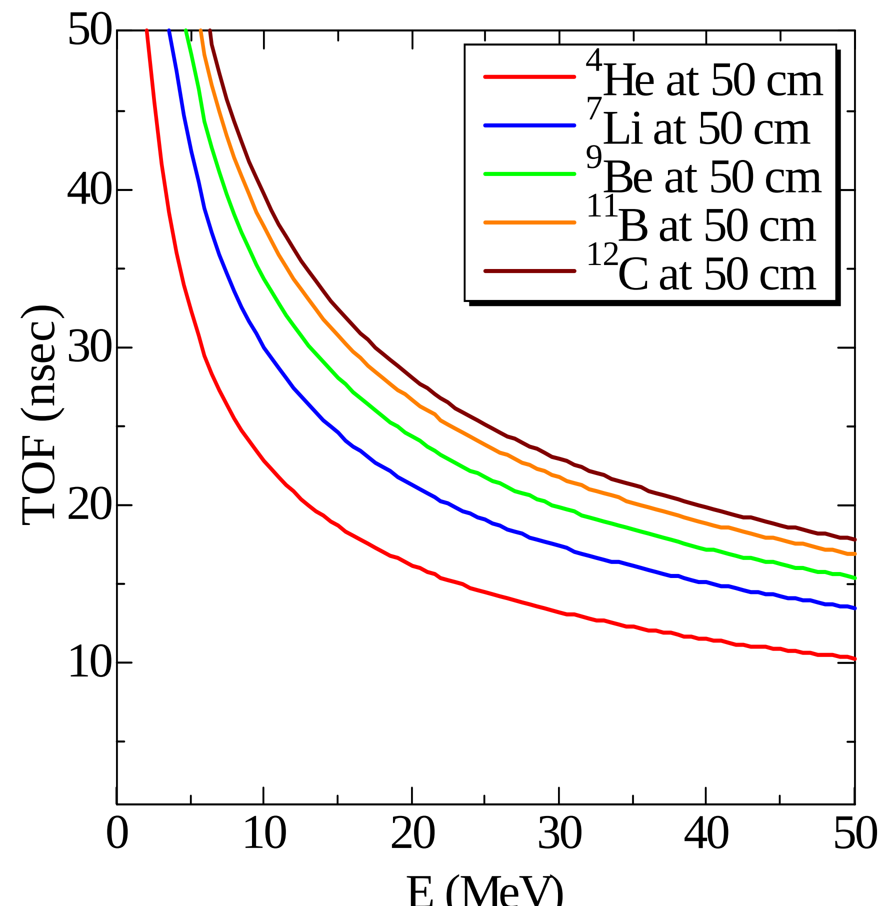
Large energy range

Very small solid angle !



$$E = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{L}{t}\right)^2$$

$$t = \frac{1}{L}\sqrt{\frac{2E}{m}}$$

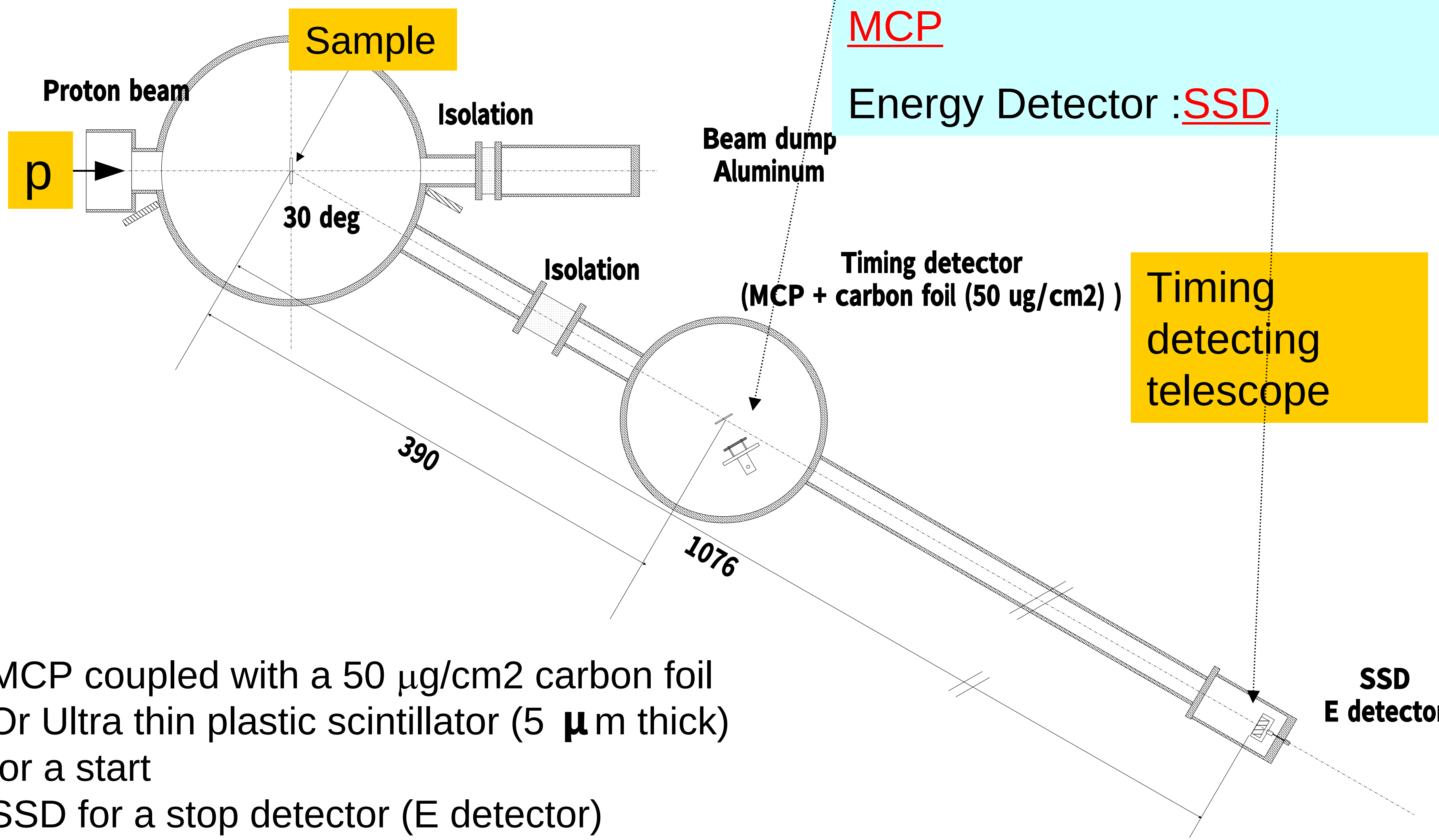


5-2. E-TOF Setup

Timing Detector :

Ultra thin plastic scintillator or MCP

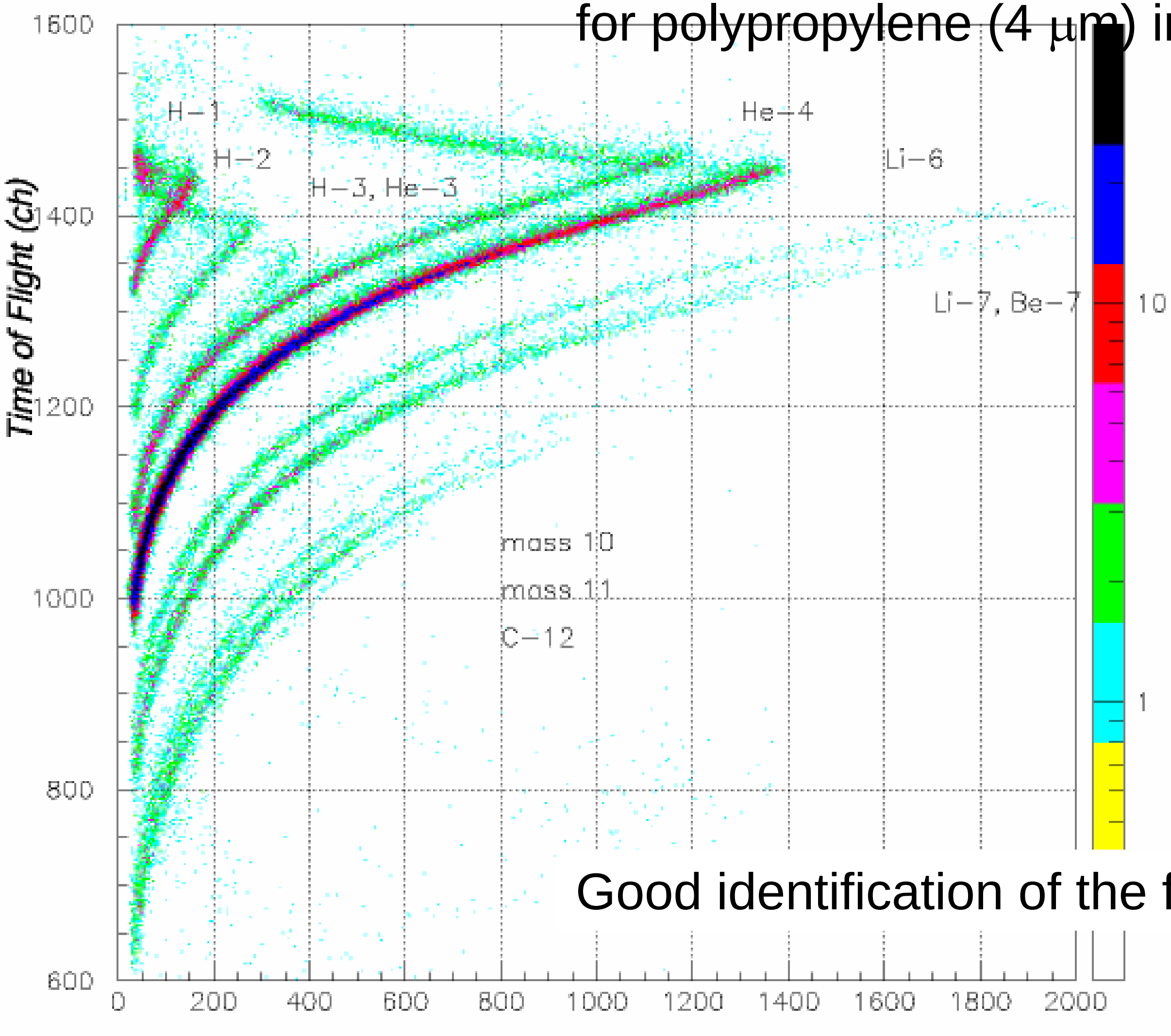
Energy Detector :SSD



MCP coupled with a 50 μg/cm2 carbon foil
Or Ultra thin plastic scintillator (5 μm thick) for a start
SSD for a stop detector (E detector)
0.7 m flight path

5-3 Results (E-TOF)

Energy *vs* TOF two-dimensional spectrum
for polypropylene (4 μm) induced by 70 MeV protons.

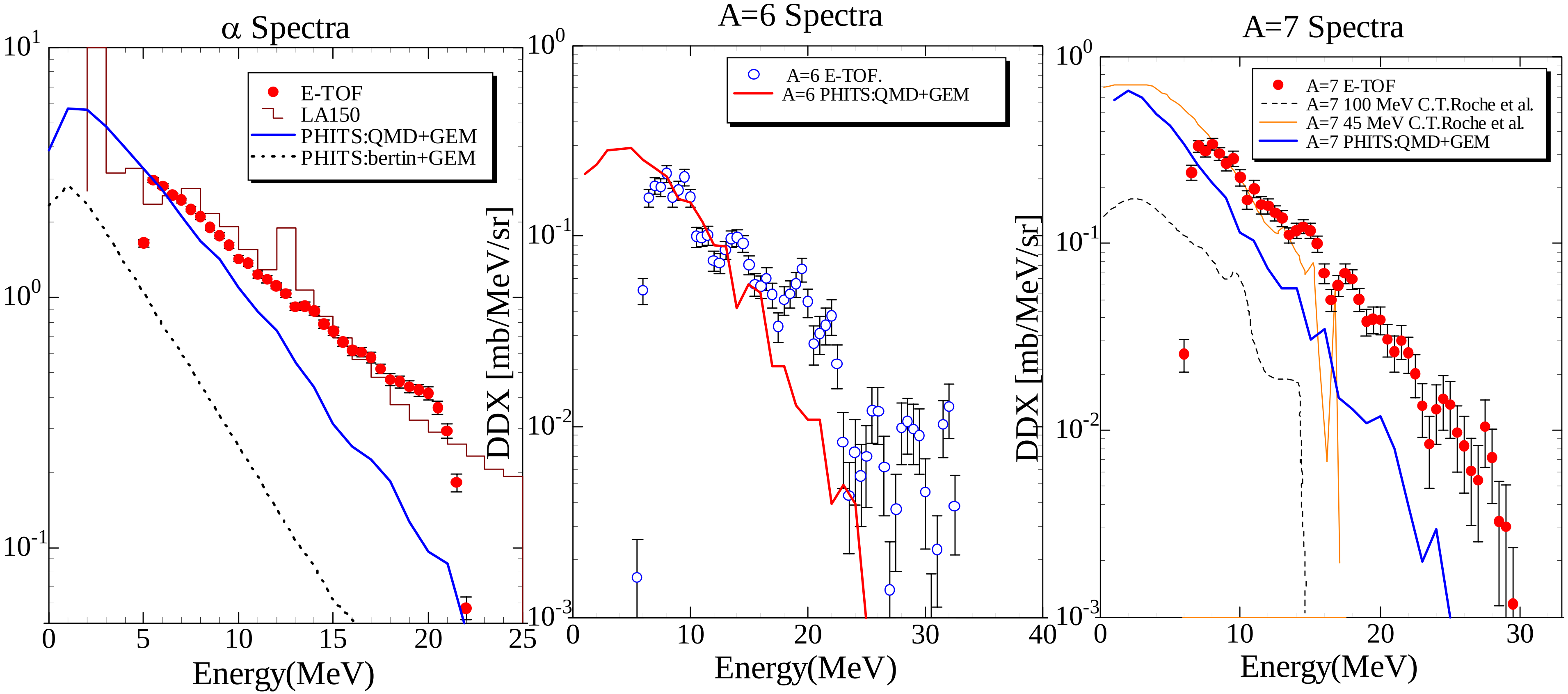


Good identification of the fragments up to A=12

5-3 Results (E-TOF)

Target: Polypropylene (4 μm)
At 30 deg.

For alpha LA150 good agreement
JQMD similar shape but
underestimation in high energy region



6. Summary

1. The present status of fragment experiment described for our group together with other facility.

2. Energy-angular distribution measurements were done with
   - A) BCS in neutron -induced reaction and proton
   - B) E-TOF method in Proton-induced reaction

2-1. BCS
- applicable not only for proton-induced reactions but also neutron-induced reactions
- DDX data were obtained by thin targets.

2-3. E-TOF
- The good identification were found in wider energy range in test exp.
- The DDX data were obtained by thin targets.

3. Improvement and extension will be done for fragment production, and the data will be applied for the analysis of SEU and dose contribution